Book of Abstracts

9th East-Asia School and Workshop

on Laboratory, Space, and Astrophysical Plasmas

(EASW9)

July 29 - August 2, 2019

Nagoya University, Nagoya, Japan

The conference is held under the auspices of Graduate School of Science and Institute for Space-Earth Environmental Research (ISEE), Nagoya University.

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EASW9 Agenda Time Table (July 10, 2019)

	Jul 29 (Mon)	Jul 30 (Tue)	Jul 31 (Wed)	Aug 1 (Thu)	Aug 2 (Fri)
08:00-	Registration				
08:45- 09:00	Opening				
09:00- 10:30	L1 Q. Lu (USTC)	L3 S. Liu (PMO)	L5 A. Lazarian (UW)	L7 Y. Idomura (JAEA)	L9 K. Shiokawa (NU)
Break					
11:00- 12:45	S-1 J. Yoo Y. Kuramitsu Jun Lin 1 contributed Photo	S-2 S. J Tanaka D. Ryu X. Zhou 2 contributed	S-3 Y. Asahina J. Zhao Y. Shen 2 contributed	S-5 Y. Ren S. Yi K. Nagaoka 2 contributed	L10 S. Inutsuka (NU) (~12:30)
Lunch break					Adjourn
14:00- 15:30	L2 Y. In (UNIST)	L4 T. Takeuchi (NU)	L6 A. Fujisawa (Kyushu U)	L8 H. Hotta (Chiba U)	
Break					
16:00- 18:00	Poster Session (~18:30)	L4 continue (~17:30)	S-4 J.-M. Kwon Y. Masada S. Zenitani 3 contributed	S-6 S. Xu T. Inoue H. Tanabe 3 contributed	
18:00- 20:00		Banquet			

EASW9 Program

(ver. 5, July 13, 2019)

Monday, July 29, 2019

8:00	**-**	**8:45**				**Registration**
8:45	**-**	**9:00**		**Opening session**		
						Opening address
						Logistics
				Lecture L1		
9:00	**-**	**10:30**	L-1	Quanming Lu (USTC, China)	90	Magnetic Reconnection in Collisionless Magnetic Reconnection
10:30	**-**	**11:00**				**Coffee Break**
				Session S1		
11:00	**-**	**12:30**		**Chair: K. Ida (NIFS, Japan)**		
11:00	-	11:25	I-1	Jongsoo Yoo (PPPL, USA)	20+5	Whistler and lower-hybrid wave during magnetic reconnection in space and laboratory plasmas
11:25	-	11:50	I-2	Yasuhiro Kuramitsu (Osaka Univ., Japan)	20+5	Energetic Ion Acceleration by Irradiating a Large-Area Suspended Graphene with Intense Lasers
11:50	-	12:15	I-3	Jun Lin (YNAO, China)	20+5	Turbulent Properties of Magnetic Reconnection in the CME/Flare Current Sheet
12:15	-	12:30	O-1	K. Kusano (Nagoya Univ., Japan)	10+5	Predictability of imminent giant solar flares based on the triggered instability model
12:30	**-**	**12:45**				**Group photo**
12:45	**-**	**14:00**				**Lunch**
				Lecture L2		
14:00	**-**	**15:30**	L-2	L-2 Yongkyoon In (UNIST, Korea)	90	Magnetohydrodynamics (MHD) in Fusion Plasmas
15:30	**-**	**16:00**				**Coffee Break**
16:00	**-**	**18:30**		**Poster Session**		

Tuesday, July 30, 2019

				Lecture L3		
9:00	**-**	**10:30**	L-3	Siming Liu (PMO, China)	90	Particle Acceleration in Astrophysics
10:30	**-**	**11:00**				**Coffee Break**
				Session S2		
11:00	**-**	**12:45**		**Chair: T. Amano (U. Tokyo, Japan)**		
11:00	-	11:25	I-4	Shuta J Tanaka (Aoyama Gakuin Univ., Japan)	20+5	Induced Compton Scattering in Pulsar Magnetospheres and Up-to-date Laser Facilities
11:25	-	11:50	I-5	Dongsu Ryu (UNIST, Korea)	20+5	Proton Acceleration at Shocks in High-beta Plasmas of Galaxy Clusters
11:50	-	12:15	I-6	Xiaowei Zhou (PMO, China)	20+5	Coherent emission driven by energetic ring-beam electrons in the solar corona

12:15	-	12:30	O-2	N. K. Walia (Univ. Tokyo, Japan)	10+5	A Statistical Study of Slow-Mode Shocks Observed by MMS in the Dayside Magnetopause
12:30	-	12:45	O-3	T. Igarashi (Chiba Univ., Japan)	10+5	Global Three-dimensional Radiation Magnetohydrodynamic Simulations of the Time Variabilities of X-ray Emitting Region in Seyfert Galaxies
12:45	**-**	**14:00**				**Lunch**
				Lecture L4		
14:00	-	15:30	L-4	Tsutomu Takeuchi (Nagoya Univ., Japan)	90	Astroinformatics: Data Science in Astrophysics
15:30	**-**	**16:00**				**Coffee Break**
				Lecture L4		
16:00	-	17:30	L-4	Tsutomu Takeuchi (Nagoya Univ., Japan)	90	Astroinformatics: Data Science in Astrophysics (continued)
18:00	**-**					**Banquet**

Wednesday, July 31, 2019

				Lecture L5		
9:00	**-**	**10:30**	L-5	Alex Lazarian (Univ. Wisconsin, USA)	90	MHD Turbulence in Astrophysical Fluids
10:30	**-**	**11:00**				**Coffee Break**
				Session S3		
11:00	**-**	**12:45**		**Chair: Dongsu Ryu (UNIST, Korea)**		
11:00	-	11:25	I-7	Yuta Asahina (Kyoto Univ., Japan)	20+5	General Relativistic RMHD simulations of Accretion Flows
11:25	-	11:50	I-8	Jinsong Zhao (PMO, China)	20+5	Nonlinear wave evolution and application to solar-terrestrial environment
11:50	-	12:15	I-9	Yuandeng Shen (YNAO, China)	20+5	Generation mechanisms of low-frequency waves in the solar corona
12:15	-	12:30	O-4	T. Katou (U. Tokyo, Japan)	10+5	Stochastic Shock Drift Acceleration Model with Finite Pitch-Angle Anisotropy
12:30	-	12:45	O-5	Z.-D. Shi (PMO, China)	10+5	Origin of Cosmic Ray Electrons and Positrons
12:45	**-**	**14:00**				**Lunch**
				Lecture L6		
14:00	-	15:30	L-6	Akihide Fujisawa (Kyushu Univ., Japan)	90	Turbulence in fusion and laboratory plasmas
15:30	**-**	**16:00**				**Coffee Break**
				Session S4		
16:00	**-**	**18:00**		**Chair: Quanming Lu (USTC, China)**		
16:00	-	16:25	I-10	Jae-Min Kwon (NFRI, Korea)	20+5	Global Structures of Flows in Tokamak Plasmas
16:25	-	16:50	I-11	Yohei Masada (Aichi Univ. Education, Japan)	20+5	Generation of Large-scale Field in Stars and Supernova Cores

16:50	-	17:15	I-12	Seiji Zenitani (Kobe Univ., Japan)	20+5	Asymmetric magnetic reconnection at the dayside magnetopause
17:15	-	17:30	O-6	H. Wang (NIFS, Japan)	10+5	Nonlinear simulation of energetic particle driven geodesic acoustic mode channeling using MEGA code
17:30		17:45	O-7	Y. Kawazura (Tohoku Univ., Japan)	10+5	Ion versus electron heating in astrophysical gyrokinetic turbulence
17:45	-	18:00	O-8	B. J. Kang (SNU, Korea)	10+5	Fast ion driven drift instability in reversed shear plasmas

Thursday, August 1, 2019

				Lecture L7		
9:00	**-**	**10:30**	L-7	Yasuhiro Idomura (JAEA, Japan)	90	Gyrokinetic simulation of fusion plasma
10:30	**-**	**11:00**				**Coffee Break**
				Session S5		
11:00	**-**	**12:45**		**Chair: Jae-Min Kwon (NFRI, Korea)**		
11:00	-	11:25	I-13	Yang Ren (PPPL, USA)	20+5	Experimental Observation of Electron-scale Turbulence Evolution across the L-H Transition in National Spherical Torus Experiment
11:25	-	11:50	I-14	Sumin Yi (NFRI, Korea)	20+5	Zonal flow generation by potential vorticity mixing in rotating tokamak plasmas
11:50	-	12:15	I-15	Kenichi Nagaoka (NIFS, Japan)	20+5	Energetic particle transport induced by wave-particle interactions in a torus plasma
12:15	-	12:30	O-9	Y.W. Cho (SNU, Korea)	10+5	Influence of Energetic Ions on Residual Zonal Flow
12:30	-	12:45	O-10	S. Maeyama (Nagoya Univ., Japan)	10+5	Subgrid-scale modeling based on Mori-Zwanzig formalism
12:45	**-**	**14:00**				**Lunch**
				Lecture L8		
14:00	-	15:30	L-8	Hideyuki Hotta (Chiba Univ., Japan)	90	Solar and stellar dynamos
15:30	**-**	**16:00**				**Coffee Break**
				Session S6		
16:00	**-**	**18:00**		**Chair: Siming Liu (PMO, China)**		
16:00	-	16:25	I-16	Siyao Xu (Univ. Wisconsin, USA)	20+5	Turbulent Dynamo in a Weakly Ionized Medium
16:25	-	16:50	I-17	Tsuyoshi Inoue (Nagoya Univ., Japan)	20+5	Plasma Dynamics in Interstellar Molecular Clouds
16:50	-	17:15	I-18	Hiroshi Tanabe (Univ. Tokyo, Japan)	20+5	Experimental study of reconnection heating/transport process and its application to high temperature spherical tokamak formation
17:15	-	17:30	O-11	R. Enokiya (Nagoya Univ., Japan)	10+5	Molecular clouds associated with magnetic features in the Galactic Center

17:30		17:45	O-12	J.-H. Ha (UNIST, Korea)	10+5	Electron Pre-acceleration at Shocks in High-beta Plasmas of Galaxy Clusters
17:45	-	18:00	O-13	M. Shi (Shandong Univ., China)	10+5	Synthetic Ultraviolet Emissions from Coronal Loops Supporting Fast Sausage Modes

Friday, August 2, 2019

				Lecture L9		
9:00	**-**	**10:30**	L-9	Kazuo Shiokawa (Nagoya Univ., Japan)	90	Ionospheric Plasma
10:30	**-**	**11:00**				**Coffee Break**
				Lecture L10		
11:00	-	12:30	L-10	Shu-ichiro Inutsuka (Nagoya Univ., Japan)	90	Phase Transition Dynamics of ISM: The Formation of Molecular Clouds and Galactic Star Formation
12:30						**Adjourn**

EASW9 Poster Sessions Program

Poster Session

P-1 – P-20: Laboratory Plasmas

P-21 – P-37: Space Plasmas

P-38 – P-51: Astrophysical Plasmas

P-52 – P-57: Interdisciplinary Topics

O-1 – O-13: Posters of Contributed Oral Talks

Poster Board ID	Presentation ID	Presenter	Title
1	P-1	M. Megalingam (VIT Univ., India)	Formation of Virtual Anode and potential well along with its fluctuation characteristics in presence of plasma bubbles in unmagnetized and magnetized plasma
2	P-2	K. Ida (NIFS, Japan)	A change of parity at the MHD collapse event of tongue in magnetically confined laboratory plasma
3	P-3	L. Chang (Sichuan Univ., China)	Wave Physics Computations in Helicon Plasmas
4	P-4	J. Bak (U. Tokyo, Japan)	Electron cross-field drift by an induced electric-field in Hall thrusters: from plasma density and potential correlation
5	P-5	Z. Shaikh (Saurashtra Univ., India)	Multi-cusp Plasma Device (MPD) for confining contact ionized alkali ions: source for the experimental studies
6	P-6	C. H. Wu (NCKU, Taiwan)	Measurement of high frequency fluctuations in Langmuir wave supercontinuum phenomenon
7	P-7	Z. Lee (NCKU, Taiwan)	Experimental Demonstration of Langmuir Wave Supercontinuum Generation in Laboratory Plasma
8	P-8	Y.-T. Lin (NCKU, Taiwan)	Experimental verification of entropy cascade in gyro-kinetic turbulence by velocity space measurement
9	P-9	A. D. Patel (IPR, India)	Study of plasma state in a versatile multi-pole cusp magnetic field
10	P-10	Y. J. Kim (SNU, Korea)	Eigenmode Analysis of the Fast Ion Driven Drift Instability in Reversed Shear Plasmas
11	P-11	K. Ueda (U. Tokyo, Japan)	Modeling of high-beta plasma equilibria in RT-1 by anisotropic-pressure MHD model
12	P-12	M. Nunami (NIFS, Japan)	Gyrokinetic Simulations for Turbulent Particle Transport of Multi-Species Plasmas in Toroidal Systems
13	P-13	H. Igami (NIFS, Japan)	Excitation and propagation of waves in ion cyclotron harmonics and lower hybrid wave frequency range originated from high energy and low pitch angle ions in a magnetically confined fusion oriented device
14	P-14	K. Nishioka (Nagoya Univ., Japan)	Dependency of turbulent transport on various local parameters in high temperature tokamak plasmas by using the analysis of electromagnetic micro-instability
15	P-15	Y. Maeshima (Nagoya Univ., Japan)	MHD Nonlinear Simulation of ELM current and pressure profile relaxation in a tokamak pedestal
16	P-16	Y. Takemura (Nagaoka Univ. Tech., Japan)	Experimental study of plasma response to pulsed magnetic field
17	P-17	K. Kondo (QST, Japan)	Plasma Shape Reconstruction by M-CCS Method in Plasma Merging Experimental Device

18	P-18	H. Kaneko (U. Tokyo, Japan)	Simultaneous measurement of high frequency magnetic fluctuation and the slowly-changing magnetic field during reconnection
19	P-19	K. Kusano (U. Tokyo, Japan)	Local Potential Measurement during High-Guide-Field Reconnection by using Langmuir Probe in UTST
20	P-20	T. Mihara (U. Tokyo, Japan)	Measurement of Soft X-ray emission spatial distribution during high guide field reconnection in UTST
21	P-21	P. Devi (Kumaun Univ., India)	Dynamics of an M3.7 Class Solar Flare on 02 March, 2015
22	P-22	K. Fan (USTC, China)	The effects of thermal electrons on whistler-mode waves excited by anisotropic hot electrons: Linear theory and 2-D PIC simulations
23	P-23	C. Umegaki (U. Tokyo, Japan)	Spatial structure of coherent whistler mode wave packets in Earth's bow shock: MMS observation
24	P-24	K. Takahashi (Kyoto Univ., Japan)	Relativistic electron acceleration by whistler-mode chorus waves in 1D, 2D, and 3D magnetic field models
25	P-25	T. Sekine (Kyoto Univ., Japan)	Relativistic acceleration of energetic protons by electromagnetic ion cyclotron waves in the Jovian magnetosphere
26	P-26	S. Sebastian (MGU, India)	Solitary Wave in a Pair Ion Plasma
27	P-27	T. Amano (U. Tokyo, Japan)	Observational Evidence for Stochastic Shock Drift Acceleration at Quasi-perpendicular Earth's Bow Shock
28	P-28	H. Ito (ISEE, Japan)	Flux decrease of outer radiation belt electrons associated with solar wind pressure pulse: A Code coupling simulation of GEMSIS-RB and GEMSIS-GM
29	P-29	P. H. Lin (JAEA, Japan)	Critical Parameters of Photospheric Magnetic Field to Produce Eruptive Flares in Solar Active Regions
30	P-30	T.-H. Watanabe (Nagoya Univ., Japan)	Auroral Growth and Transition to Alfvenic Turbulence in the Magnetosphere-Ionosphere Coupling
31	P-31	K. M. Girgis (Kyushu Univ., Japan)	Solar Storm Effects on South Atlantic Anomaly: Test Particle Simulations
32	P-32	Y. Nishida (Tohoku Univ., Japan)	Dependence of the Dipole Component Dominancy on the Rayleigh Number and Inner Core Size in Geodynamo Simulations
33	P-33	K. Shimomura (Nagoya Univ., Japan)	Electron beam instability in the inhomogeneous field on the collisionless magnetic reconnection with a strong guide field
34	P-34	J. Hiwatari (Nagoya Univ., Japan)	Auroral Cavity Mode with Ionospheric Inhomogeneity
35	P-35	H. Sato (Nagoya Univ., Japan)	Application of Contour Dynamics Method to the Vlasov-Poisson Plasma with the Periodic Boundary
36	P-36	K. Nakatani (ISEE, Japan)	Modeling of solar active regions using local linear force-free fields to estimate magnetic twist
37	P-37	Y. Ito (ISEE, Japan)	Dependence of whistler wave amplitudes on scattering process of relativistic electrons in the Earth radiation belts
38	P-38	S. Roh (UNIST, Korea)	Turbulence in clusters of galaxies

39	P-39	S. Kim (UNIST, Korea)	Firehose instability in Astrophysical and Space Environments
40	P-40	D. Abe (Nagoya Univ., Japan)	The MHD simulation towards a solution of filament formation and the initial condition of star formation in molecular clouds
41	P-41	R. Maeda (Nagoya Univ., Japan)	Formation of Massive Star Clusters by Fast HI Gas Collision
42	P-42	D. Mandel (IPR, India)	Tracking the linear stage of instability in finite beam plasma System
43	P-43	A. Lladrovci (Chiba Univ., Japan)	Oscillations of Accretion Disks around a Supermassive Black Hole
44	P-44	T. Kotani (Kyoto Univ., Japan)	PIC simulation on nonlinear development of lower-hybrid instabilities driven by energetic ions
45	P-45	H. Yoon (CNU, Korea)	Effect of Turbulence and sonic Mach number on Davis-Chandrasekhar-Fermi method
46	P-46	T. Tomiyoshi (Chiba Univ., Japan)	3D-MHD Simulation of Prominences Formation in the Galactic Center
47	P-47	Y. Nakanishi (Nagoya Univ., Japan)	THE FORMATION OF OVER-IONIZED PLASMA BY SUPERNOVA EXPLOSION
48	P-48	S. Masuda (ISEE, Japan)	Twenty-seven years of Nobeyama Radioheliograph: Contribution to space weather/climate researches
49	P-49	N. Nishida (Nagoya Univ., Japan)	Kinetic analysis of the interaction between high temperature plasma and low temperature gas
50	P-50	S. Nishimoto (NDA, Japan)	Construction of Solar Flare Emission Spectral Prediction Model
51	P-51	K. Matsunaga (Nagoya Univ., Japan)	Cloud-cloud collisions in a foot point of a magnetic flotation loop in the Galactic Center
52	P-52	A. Kumari (IIA, India)	Estimates of Solar Coronal Magnetic Fields with Full Stokes Observations of the Sun using LOFAR
53	P-53	Y. He (USTC, China)	A Brief Introduction of AWs and KAWs in Plasma
54	P-54	Y. Lee (Hanyang Univ., Korea)	Investigation of the parallel dynamics to determine poloidal inhomogeneity in a tokamak
55	P-55	G. Lin (NAOC, China)	A New Online Database of Filament
56	P-56	K. Deguchi (Monash Univ., Australia)	Subcritical magneto-hydrodynamic instabilities
57	P-57	T. Ito (Nagoya Univ., Japan)	Experimental research on turbulent transport in non-uniform turbulence field
58	O-1	K. Kusano (Nagoya Univ., Japan)	Predictability of imminent giant solar flares based on the triggered instability model
59	O-2	N. K. Walia (Univ. Tokyo, Japan)	A Statistical Study of Slow-Mode Shocks Observed by MMS in the Dayside Magnetopause

60	O-3	T. Igarashi (Chiba Univ., Japan)	Global Three-dimensional Radiation Magnetohydrodynamic Simulations of the Time Variabilities of X-ray Emitting Region in Seyfert Galaxies
61	O-4	T. Katou (U. Tokyo, Japan)	Stochastic Shock Drift Acceleration Model with Finite Pitch-Angle Anisotropy
62	O-5	Z.-D. Shi (Purple Mountain Observatory, China)	Origin of Cosmic Ray Electrons and Positrons
63	O-6	H. Wang (NIFS, Japan)	Nonlinear simulation of energetic particle driven geodesic acoustic mode channeling using MEGA code
64	O-7	Y. Kawazura (Tohoku Univ., Japan)	Ion versus electron heating in astrophysical gyrokinetic turbulence
65	O-8	B. J. Kang (SNU, Korea)	Fast ion driven drift instability in reversed shear plasmas
66	O-9	Y.W. Cho (SNU, Korea)	Influence of Energetic Ions on Residual Zonal Flow
67	O-10	S. Maeyama (Nagoya Univ., Japan)	Subgrid-scale modeling based on Mori-Zwanzig formalism
68	O-11	R. Enokiya (Nagoya Univ., Japan)	Molecular clouds associated with magnetic features in the Galactic Center
69	O-12	J.-H. Ha (UNIST, Korea)	Electron Pre-acceleration at Shocks in High-beta Plasmas of Galaxy Clusters
70	O-13	M. Shi (Shandong Univ., China)	Synthetic Ultraviolet Emissions from Coronal Loops Supporting Fast Sausage Modes

Collisionless Magnetic Reconnection

Quanming Lu(陆全明)
School of Earth and Space Sciences, University of Science and Technology of China

Magnetic reconnection converts magnetic energy into plasma kinetic energy, and it is considered to be related to explosive phenomena in space environment. However, in order to explain these explosive phenomena, a fast reconnection is necessary. Collisionless magnetic reconnection, or Hall reconnection, provides a possibility to fulfill fast reconnection. In collisionless magnetic reconnection, ions and electrons are decoupled, and the diffusion region consists of ion diffusion region and electron diffusion region. In the ion diffusion region, the electrons are magnetized and ions are unmagnetized, while in the electron diffusion region both ions and electrons are unmagnetized. I will review recent progresses on collisionless magnetic reconnection based on both particle-in-cell simulations and satellite observations.

Magnetohydrodynamics (MHD) in Fusion Plasmas

Yongkyoon In

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Magnetohydrodynamics (MHD) has been greatly advanced throughout the whole fusion programs, exhibiting the elegance of theory against seemingly daunting experimental results. Despite a set of vastly simplified assumptions (e.g. single fluid description rather than electron and ion fluids), both ideal and resistive MHDs have proven valid in a majority of fusion plasmas, providing an excellent infrastructure for equilibrium and stability.

Assuming the plasma resistivity ($\eta = 0$) goes to zero, ideal MHD model describes a single-fluid, low-frequency, long-wavelength, macroscopic plasma behavior. One of the strongest merits of ideal MHD description enables us to figure out the magnetic field topology which affects the macroscopic equilibrium and stability. Indeed, the knowledge and accuracy of the magnetic field configurations at equilibrium play a key role in clarifying a variety of global and local MHD instabilities. In that regard, the understanding of the validity and limitation of ideal MHD could be more important than what needs to be further elaborated.

Given the enormously rich literatures of MHD (more than thousands, if not ten-thousands, e.g. [1]), it may not be fair to list up only a few selective materials. Nonetheless, for the sake of speedy understanding for beginners in a limited time of class, a few examples in equilibrium and stability will be discussed, including Grad-Shafranov equation, tearing mode, Mercier mode and resistive wall mode (RWM).

[1] J. Freidberg, Ideal MHD, 2014

Particle Acceleration in Astrophysics

Siming Liu

Varieties of mechanisms have been proposed for the acceleration of high-energy charged particles in different astrophysical environments, such as acceleration by parallel electric fields, betatron acceleration, magnetic curvature drift acceleration, magnetic gradient drift acceleration, current drift acceleration, ion pickups, resonant wave-particle interaction, stochastic particle acceleration, first-order Fermi acceleration, second-order Fermi acceleration, acceleration via magnetic reconnection, shock acceleration, turbulence acceleration etc. Some of these mechanisms deal with the microscopic processes, while others deal with statistical properties of particle acceleration and the related macroscopic energy conversion processes. Some deal with the instantaneous state of accelerated particles, others deal with the effects of particle acceleration accumulated over time. Clarification of relations among these mechanisms is essential to address the particle acceleration problem. I will discuss these relations and exploring the origin of complexity when dealing with specific acceleration phenomena. With the prominent enrichment of 3He in solar energetic particle events as an example, I will demonstrate how quantitative modeling may be carried out.

Astroinformatics: Data Science in Astrophysics

Tsutomu T. TAKEUCHI

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Astroinformatics stands for a system of data science knowledge and techniques to handle astrophysical data. It is a modern extension of astrostatistics, in the sense that it contains computer-intensive methods in addition to traditional statistical methodology. Then, it may be roughly divided into two levels, a general methodology and special treatment of specific problems in astronomical data. In this talk, we try to review some topics from both categories. We also plan to have time for workshop with practical exercises.

MHD Turbulence in Astrophysical Fluids

Alex Lazarian

Univ. Wisconsin, USA

Astrophysical plasmas are magnetized and turbulent. Turbulence radically changes the properties of magnetized plasmas. I shall discuss both non-relativistic and relativistic turbulence at the sufficiently large scales that the MHD approximation is applicable. I shall discuss the scalings of fundamental modes of MHD turbulence, i.e. Alfven, slow and fast, and their differences in relativistic and non-relativistic cases. I shall show that the turbulence induces fast reconnection and the violation of magnetic flux freezing. Finally, I shall briefly discuss astrophysical implication of MHD turbulence.

Turbulence in fusion and laboratory plasmas

A. Fujisawa

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Magnetically confined plasmas have been studied for more than 50 years, particularly, to aim at realizing a nuclear fusion reactor. It has been the plasma turbulence to prevent us from achieving such a high performance plasma, since the turbulence enhance the cross-field transport to degrade the plasma confinement. Therefore, the turbulence has been intensively studied in the field of magnetically confined plasmas. At present many of findings have been obtained thanks to the world-wide efforts with developing new diagnostics of plasma turbulence.

One of the important findings for the fusion research should be a bifurcation phenomenon in a turbulence plasma, such as H-mode, super-shot, internal transport barrier, RI-mode, and High Density H-mode [1]. These discoveries have made us recognize that the magnetically confined plasma should be a matter to bifurcate, and that the sheared flows (radial electric field) should be a key mechanism to reduce the turbulence and resultant transport.

The other should be the discovery of zonal flows [2,3]. The zonal flows are the mesoscopic fluctuating structures symmetric around the magnetic axis, thus do not contribute to any cross-field transport. Moreover, the zonal flows are generated from the turbulence, and the energy transfer from turbulence to zonal flows improves the plasma confinement, together with their shearing of turbulence. These findings should be the beginning of the recognition of the importance of nonlinear interaction between disparate scale structures for the plasma confinement.

This lecture will describe the above-mentioned phenomena in a historical view, and the plasma turbulence diagnostics that have given new insights into the turbulence plasma. Moreover, the lecture will discuss future directions of confinement studies, and introduce a new experimental device that has been constructed for pursuing the physics of plasma turbulence, named **PLA**sma **T**urbulence **O**bservatory (**PLATO**) [4]. Finally, the fusion research of the turbulence should contribute to not only fusion research but also to understanding a number of phenomena in the universe, such as the anomalous diffusion in an accretion disk around a blackhole, solar tachocline in the sun, and the generation of magnetic field and zonal flows in a planet.

[1] A. Fujisawa, Plasma Phys. Control. Fusion **45** R1 (2003).
[2] P. H. Diamond, S-I. Itoh, K. Itoh, T. S. Hahm, Plasma Phys. Control. Fusion **47** R35 (2005).
[3] A. Fujisawa, Nucl. Fusion **49** (2009) 013001.
[4] A. Fujisawa, AIP Conference Proceedings **1993**, 020011(2018)

Gyrokinetic simulation of fusion plasma

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Fusion plasma is an extremely complex physical system consisting of multiple fluids (an electron fluid and other ion fluids) coupled with each other through electromagnetic fields and weak Coulomb collisions. Because of this complexity, computer simulations are essential in wide spectrum of fusion science. Among several critical issues, turbulent plasma transport, which dictates the size and cost of a magnetic fusion reactor, is a problem demanding the biggest computer resource.

In contrast to neutral fluid turbulence described in three-dimensional (3D) configuration space, plasma turbulence requires a treatment of a particle distribution function in 6D phase space and has been prohibitive for a long time. However, the development of the gyrokinetic model [1,2], which is a reduced kinetic model of magnetized plasmas in 5D phase space, and recent advances in supercomputers and simulation models enabled a direct numerical simulation of plasma turbulence in a toroidal configuration with experimentally relevant parameters. Such gyrokinetic simulations have been established not only as complementary approaches to obtain physical understanding but also as essential tools for predicting turbulent spectrum and transport in the experiment [3,4].

This lecture aims to overview progress in gyrokinetic simulations of turbulent fusion plasmas. Firstly, theoretical frameworks of physical models from the 6D Vlasov equation to the 5D gyrokinetic equation are presented, and then, simulation models to treat multi-scale physics in the 5D gyrokinetic equation are discussed. Secondly, properties of numerical approaches, namely, Lagrangian and Eulerian approaches are described, and a role of numerical dissipation in collisionless turbulence simulations is discussed. Thirdly, recent advances in gyrokinetic simulations are reviewed focusing on multi-scale simulations such as numerical experiments using full-f gyrokinetic models and ion-electron multi-scale electron turbulence simulations.

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Solar and stellar dynamos

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The sun has ubiquitous magnetic fields observed on the surface. A prominent magnetic feature is sunspots, which is a strong magnetic region is on the surface. The number of sunspots has interesting cyclic behavior known as the solar 11-year cycle. This magnetic field and feature are thought to be maintained by the dynamo action in the solar interior, but we have not understood the full details of the physical mechanism of the solar cycle.
Chaotic, turbulent convection fills the outer part of the solar interior. This turbulence is the key to understand the dynamo and the solar cycle. A combination of the turbulence and the rotation creates the differential rotation, which leads to a large scale bending of the magnetic field. Another combination of the turbulence and the rotation directly causes a turbulent effect for constructing large-scale magnetic fields. We need to understand all these processes simultaneously to understand the solar cycle.
In my lecture, I summarize the basic concept of the solar dynamo theory about the convection, the differential rotation, and the magnetic field. I also introduce the latest results of the theory and observation.

Ionospheric Plasma

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In this lecture, I will first introduce basic structure of the Earth's upper atmosphere. The Earth's atmosphere is divided into several layers by its temperature structure, from bottom to top, troposphere, stratosphere, mesosphere, and thermosphere. Part of the thermospheric atmosphere is ionized, forming the ionosphere, which is further divided into E and F layers. The atmospheric density, temperature, composition, and ionospheric plasma density changes depending on local time (day/night), latitudes, and solar activities. The ionospheric plasma is trapped by the geomagnetic field, making cyclotron motion, but drift by background electric field through ExB drift. The motion of ions and electrons in the ionosphere can be different because of difference in collision frequency with neutrals. This difference cause electric current in the ionosphere.

It is very difficult to measure upper atmosphere directly, because balloon can reach only up to 50 km, and satellites below 300 km easily fall down due to air drag force. Thus, various remote-sensing techniques have been developed to measure the upper atmosphere. I will introduce these various techniques. The techniques contains, ionosonde, coherent/incoherent scatter radar, airglow imager, Fabry-Perot interferometer, GNSS receiver, magnetometer, and satellites.

Then I will introduce two major forces that cause dynamic variations of the F-region ionosphere at middle latitudes, which are meridional neutral wind and zonal electric field. Dynamical variations of the F-region ionosphere during geomagnetic storms are mainly caused by these two forces. The north-south neutral wind is a slow process with a time scale of ~hour, and propagate from high to low latitudes. On the other hand, east-west electric field is a fast process with a time scale of seconds to minutes, and can be simultaneous on global scale. The latter process is usually directly associated with geomagnetic disturbances. In the daytime ionosphere, the upward motion of the F-layer due to these two processes is the origin of positive ionospheric storm due to less recombination at higher altitudes.

The effect of geomagnetic storms on the thermosphere and the ionosphere at middle and low latitudes is important. The meridional neutral wind effect can be identified as large-scale traveling ionospheric disturbances (LSTIDs). The electric field effect may be recognized as the sudden enhancement of electron density at low latitudes or sudden height variation of the ionosphere that coherently occur at different locations. In addition, decrease of O/N_2 ratio (increase of N_2 molecule in the thermosphere due to auroral zone heating) can cause negative ionospheric storms at middle and low latitudes during main and recovery phase of the storms.

Then I will also introduce several non-storm disturbances in the upper atmosphere. The equatorial plasma bubbles and nighttime mid-latitude medium-scale traveling ionospheric disturbances (MSTIDs) are two distinct phenomena in the non-storm time ionosphere, which affect significantly to the GNSS positioning. These two phenomena are mainly caused by ionospheric Rayleigh-Taylor-type instabilities. I will explain details of the instabilities. Then, the effect of atmospheric waves are reviewed. The atmospheric waves can be categorized as (1) sound waves (period <5 min, compressional, local), (2) gravity waves (period: 5min - several hours, shear type, regional), (3) tides (period: 6 hours – 1 day, shear type, global (earth-scale resonance)), and (4) planetary waves (period: a few days – 16 days, shear type, global, including the effect of Corioli's force).

In summary, neutral-plasma interaction is a persistent boundary field where a lot of unsolved but important questions exists. For the atmospheric waves from the bottom, question arises on how atmospheric waves penetrate into the ionosphere and initiate/modulate ionospheric instabilities? The question includes bubble/large-scale wave interaction, day-to-day variability of bubbles, mid-latitude MSTID motion, inter-hemispheric coupling of MSTIDs/bubbles through field-aligned currents in the plasmasphere, and tides/planetary wave penetration. As for the energy input from the magnetosphere, question arises on how the high-latitude energy input changes the ionospheric dynamics and composition? The question includes electric field and equatorward wind for plasma fountain, vertical wind near aurora, feedback to the plasma convection in the magnetosphere, and atmospheric composition change and transport. Finally I would like to note that when human beings start to live in space, research on the upper atmosphere would become much closer to our daily life, like a Space Meteorology".

Phase Transition Dynamics of ISM: The Formation of Molecular Clouds and Galactic Star Formation

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Magnetohydrodynamics of interstellar medium is remarkably different from that of simple barotropic gas owing to the phase transitions between cold phase and warm phase (and hot phase) that trigger variety of instabilities. Identifications of distinct instabilities in various stages provide us important clues for understanding the saturation levels of turbulent energies and rates of formation and destruction of cold clouds, such as HI clouds and molecular clouds. Recent high-resolution magneto-hydrodynamical simulations of phase transition dynamics with cooling/heating and thermal conduction have shown that the formation of molecular clouds requires multiple episodes of supersonic compression. This finding enables us to create a new scenario of molecular cloud formation as the interacting shells or bubbles in galactic scale, which explains many observational properties such cloud-to-cloud velocity dispersions, accelerating star formation, and very low star formation efficiencies in filamentary molecular clouds. We estimate the ensemble-averaged growth rate of individual molecular clouds, and predict the associated cloud mass function. Cloud-cloud collisions as a mechanism for forming massive stars and star clusters can be naturally accommodated in this scenario. This explains why massive stars formed in cloud-cloud collisions follows the power-law slope of the mass function of molecular cloud cores repeatedly found in low-mass star forming regions [1].

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Whistler and lower-hybrid wave during magnetic reconnection in space and laboratory plasmas

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Whistler and lower hybrid waves during asymmetric magnetic reconnection are studied with data from the Magnetospheric Multiscale (MMS) mission and the Magnetic Reconnection Experiment (MRX). In particular, the dispersion of the whistler mode (~$0.5f_{ce}$) near the magnetospheric (low-density) separatrix is measured for the first time [1]. The measured dispersion relation shows that the whistler wave propagates nearly parallel to the magnetic field. It is also consistent with the theoretical dispersion relation from a linear analysis. The linear analysis confirms that the whistler wave is generated by temperature anisotropy in the electron tail population. The temperature anisotropy is caused by the loss of electrons with a high velocity parallel to the magnetic field to the exhaust region [2]. We also have observed in both space and laboratory plasmas that the lower-hybrid drift wave (LHDW) is excited inside the current sheet during reconnection with a sizable guide field. The LHDW propagates almost perpendicular to the magnetic field. Moreover, the LHDW is capable of inducing density fluctuations that are in phase with electric field fluctuations, generating anomalous resistivity in the current sheet. A new theoretical model has been developed to explain the excitation of the LHDW, which shows that the high electron current is the free energy source for the wave. A similar lower-hybrid wave is also observed in the MRX current sheet with a high guide field.

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Energetic Ion Acceleration by Irradiating a Large-Area Suspended Graphene with Intense Lasers

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We have been working on laboratory astrophysics, where space/astrophysical phenomena are experimentally simulated with high-power lasers. In laboratories one can access the local and global information in a controlled manner[1]. One of the key diagnostics is proton radiography to image electric and magnetic fields in laser-produced plasmas. In order to efficiently accelerate ions we have developed a large area suspended graphene (LSG), which is the thinnest, lightest, strongest and transparent target[2]. We have been developing energetic ion sources with the LSG not only for plasma diagnostics but also for medical and industrial applications. We will report our recent progress on the laser driven ion sources with the LSG.

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TURBULENT PROPERTIES OF MAGNETIC RECONNECTION IN THE CME/FLARE CURRENT SHEET

By Jun Lin of Yunnan Astronomical Observatories, CAS, China

The current sheet formed in the disrupting magnetic configuration during the solar eruption is always at a highly dynamic state, both globally and locally. It grows at a speed up to a few hundred km/s in its length, and a long current sheet is usually unstable to several types of plasma instabilities. Among these instabilities, the tearing mode instability is the most important one since it is a long wavelength disturbance and the restoring force produced by the deformed magnetic field is weakest. Development of the tearing mode instability consequently results in turbulence inside the current sheet, and makes the current sheet itself be an assembly of various micro processes and the related structures. These structures play an important role in enhancing the dissipation and allows magnetic reconnection to occur at a reasonably fast rate is a fairly thick CS. In this work, we are going to display prominent features of various structures observed in the solar eruption and numerical experiments, and to discuss their roles in the eruption, together with the associated magnetic reconnection process.

Induced Compton Scattering in Pulsar Magnetospheres and Up-to-date Laser Facilities

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One of the most famous objects in the high-energy astrophysics is the Crab Nebula. Numerous observational results of the Crab Nebula suggest that the Crab Nebula is powered by its central pulsar. The Crab Nebula is composed of the relativistic magnetized plasmas supplied from the Crab pulsar, called pulsar wind, and is illuminating from radio wavelength through TeV gamma-rays. However, the origin and the driving mechanism of the pulsar wind is still unclear.

The winds, i.e., supersonic plasma outflows, from the astrophysical objects are popular phenomena. The pulsar wind is characterized by its density, velocity and magnetization. The standard magnetohydrodynamic model of the Crab Nebula [1, 2] suggest that the Crab's pulsar wind is the ultra-relativistic (the bulk Lorentz factor of $\sim 10^6$) and magnetically subdominant (the ratio of the magnetic to kinetic energy flux of $\sim 10^{-3}$) flow at its terminal Corresponding total number flux of the plasma particle is $\sim 10^{49}\ \mathrm{s}^{-1}$. However, the standard model is not enough to explain the whole observations of the Crab and the above numbers are still under discussion [e.g., 3, 4].

Here, we introduce one of the fundamental laser-plasma nonlinear interaction, called induced Compton scattering, in order to explore the physical properties of the pulsar wind. The brightness temperature of the Crab pulsar's radio emission has attained to 10^{37}K and then the Crab pulsar is considered as the laser facility in nature. The interaction of this coherent radio emission with the pulsar wind plasma is expected around the pulsar's magnetosphere [5]. The dominant interaction will be induced Compton scattering and the non-detection of the scattering feature from the Crab's radio emission constrains the density of the Crab pulsar wind [6]. We also introduce possible experiments of induced Compton scattering in present laboratories. Further understanding of induced Compton scattering will be an interesting tool to resolve the long-standing problem of the astrophysics, i.e., the driving mechanism of the pulsar wind.

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Proton Acceleration at Shocks in High-beta Plasmas of Galaxy Clusters

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Shock waves with low sonic Mach number are induced by mergers and/or supersonic flow motions in the hot tenuous plasmas of the intracluster medium (ICM). High-energy cosmic ray (CR) protons are expected to be accelerated at quasi-parallel shocks via diffusive shock acceleration (DSA), while proton acceleration is suppressed at quasi-perpendicular shocks. The key element of DSA is the so-called injection process, which energizes thermal protons to the suprathermal energies sufficient to diffuse across the shock. We first present a study of CR injection and early acceleration at weak quasi-parallel ICM shocks using particle-in-cell (PIC) simulations. We then present an analytic model that describes the energy spectrum of CR protons accelerated in ICM shocks. Finally we discuss the implications of this work on gamma-ray observation in clusters of galaxies.

Coherent emission driven by energetic ring-beam electrons in the solar corona

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We investigate the wave excitation properties driven by an unstable ring-beam electron distribution in a uniform magnetic field, such as the saturation, anisotropic intensity of different wave modes as well as the polarization and its anisotropy. With the ring-beam distribution, free energies for emission exists in both parallel ($u_{\parallel} \cdot df/du_{\parallel} > 0$) and perpendicular ($df/du_{\perp} > 0$) directions to the ambient magnetic field, where f indicates the electron distribution function. These free energies can trigger beam and electron cyclotron maser (ECM) instabilities, respectively, which can enhance intensities of electromagnetic waves in plasmas with respect to the normal isotropic equilibrium Maxwellian plasmas. Because the beam and ECM instabilities are kinetic processes, 2.5D particle in cell (PIC) simulations are used for this study. Contributions of these two instabilities on different wave mode excitations are studied in detail. For the excitation characteristics at different locations along the trajectory of the ring-beam electrons in the solar corona, emission properties dependence on the number density ratio between the ring-beam and total electrons n_{rb}/n_t as well as the frequency ratio between the electron cyclotron frequency ω_{ce} and the electron plasma frequency ω_{pe} are discussed.

General Relativistic RMHD simulations of Accretion Flows

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Elongated, narrow structures called astrophysical jets are observed in active galaxies, galactic microquasars, star-forming regions, and so on. In order to reveal the formation mechanism of jets and the structure of accretion flows, many simulations have been performed. Ohsuga et al. (2009) first performed multi-dimensional radiation hydrodynamic simulations of an accretion flow around the black hole [1]. They revealed that the radiation is important for simulating the jet formation and structures of an accretion disk exactly. The general relativistic effects should be considered since the jet formation and disk accretion are phenomena nearby the black hole. Sadowski et al. (2014) and Takahashi et al. (2016) are take account of the general relativistic effects by performing general relativistic radiation magnetohydrodynamical (GRRMHD) simulations [2] [3]. They show that the jet is accelerated by strong radiation pressure and collimated by the magnetic field. We need to perform GRRMHD simulations of the accretion flow since all of the radiation, magnetic fields, and general relativistic effects are important.

Previous studies adopted an approximation method to solve the radiative transfer, for example, the Flux limited diffusion (FLD) approximation or the first moment (M1) method. These methods cannot solve the radiative transfer exactly in the optically thin region (e.g. the collision between radiations). In order to solve the radiative transfer more exactly, we develop a GRRMHD code based on solving the Boltzmann equation. We solve a conservative form of the Boltzmann equation in general relativity [4]. When we solve the radiative transfer, we need to determine the radiation pressure. For the M1 method, the radiation pressure is estimated from radiation energy density and radiation energy flux approximately. On the other hand, for our method, we can determine the radiation pressure from the specific intensity without any assumptions since we have the specific intensity obtained by solving the Boltzmann equation.

We perform GRRMHD simulations of accretion flows using this code. At the initial state, we assume the equilibrium torus [5], small isotropic radiation energy density, and the weak poloidal magnetic field inside the torus. The differential rotation in the torus enhances the toroidal magnetic field and the magnetorotational instability (MRI) grows up inside the torus. The angular momentum is transported by the MRI and then the mass accretion rate suddenly increases. The difference of the radiation field appears around the rotation in the optically thin region. For the M1 method, the radiation from the accretion flow collides with each other unphysically around the rotation axis. For our method, such unphysical collision doesn't occur. We report the result of simulations with the various initial density profile, the strength of the magnetic field, and spin parameter of the black hole.

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Nonlinear wave evolution and application to solar-terrestrial environment

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The nonlinear wave-wave interaction is a basic process in plasma physics. Recently, many theoretic and numerical studies have paid attention to the nonlinear evolution of two basic wave modes, that is, Alfvén and whistler waves, in space plasmas. Here we present two-dimensional (2D) and three-dimensional (3D) nonlinear instabilities of Alfvén/whistler waves basing on the fluid model. The decay instability of the Alfvén wave is controlled by the joined action of the scalar and vector interactions. In application to the broadband Alfvén waves in the solar wind, the vector nonlinear coupling dominates in the extended wavenumber range $5 \times 10^{-4} \sim< \varrho_i k_{0\perp} \sim< 1$ [1], where the decay is essentially 3D and nonlocal, generating product Alfvén and slow waves around the ion gyroscale. ϱ_i is the ion gyroradius, and $k_{0\perp}$ is the pump Alfvén wavenumber. Evaluation of the nonlinear frequency shift shows that product Alfvén waves can still be approximately described as normal Alfvénic eigenmodes. On the contrary, nonlinearly driven slow waves deviate considerably from normal modes and are therefore difficult to identify on the basis of their phase velocities and/or polarization. On the other hand, the whistler decay instability can excite waves with a broadband wavenumber spectrum, including highly oblique propagating whistler waves. Whistler waves produce both co- and counter- propagating whistler waves. 3D instabilities have similar nonlinear growth rate distributions as in 2D decay for the azimuthal wavelength much larger than λ_e [2]. These results suggest that nonlinear wave–wave interaction can play an important role in the scattering of whistler waves in the solar wind and the Earth's magnetosphere.

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Generation mechanisms of low-frequency waves in the solar corona

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The generation mechanisms of low-frequency wave in the solar corona will be introduced in detail, especially advances in recent years based on high temporal and high spatial resolution observations. The talk mainly introduces the generation mechanisms of two kinks of low-frequency coronal waves including the large-scale extreme ultraviolet (EUV) waves and the quasi-periodic fast-propagating magnetosonic waves. The large-scale EUV waves were discovered twenty years ago in the SOHO era, but question about their generation mechanism is still not completely understood. The main discrepancy about the driving mechanism of EUV waves is whether they are driven by flare pulses or coronal mass ejections (CMEs). Many previous studies have suggested that EUV waves are not driven by flare pulses; therefore, their driver should be CMEs. Many recent high resolution observations did support the CME driven theory. Nevertheless, there should have other driving mechanisms of large-scale EUV waves, because any disturbance would launch waves in the solar corona in theory. By searching the 7-years database of SDO/AIA, we did find new driving mechanisms of EUV waves in some non-CME-association eruptions. For example, large-scale EUV waves can be driven by coronal jets directly, sudden loop expansions due to the impingement of other disturbances, and periodic expanding motion of the unwinding helical structure of erupting solar filaments. These new results enhanced our understanding of coronal EUV waves. The quasi-periodic fast-propagating waves were detected by the SDO/AIA, and they are tightly associated with quasi-periodic pulsation in solar flares. We will introduce the several possible excitation mechanisms in theory and the corresponding observation evidences.

Global Structures of Flows in Tokamak Plasmas

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To predict the performance of fusion machine such as tokamak, it is critical to understand the physics of plasma turbulence and flow. In this presentation, we report recent progresses in theoretical and experimental studies of plasma flows in KSTAR tokamak. Firstly, we present gyrokinetic simulation studies for the effects of external magnetic fields on plasma flow in a KSTAR L-mode discharge. It is shown that a (2,1) magnetic field induced by the external fields changes the structures of poloidal plasma flows and these changes affect the ambient plasma fluctuations and resulting transports[1]. Along with these simulations, we also present 2D ECEI measured electron temperature fluctuations in the corresponding KSTAR L-mode discharge, which reveals the structures of plasma flows around the (2,1) magnetic island[2]. It is found that the flow structures from the gyrokinetic simulations are consistent with the experimental ones. Secondly, we report 2D ECEI measurement of electron temperature fluctuations in a MHD-free KSTAR L-mode plasma, which reveals quasi-static corrugations in the electron temperature profile and also hints the existence of zonal flow shearing layers corresponding to the corrugations[3]. Very interestingly, it is found that global gyrokinetic simulations employing the experimental condition also show similar corrugation patterns and zonal flow shearing layers. More detailed results and implications of them will be discussed in the presentation.

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Generation of Large-scale Field in Stars and Supernova Cores

In our talk, we discuss the generation process of the mean-field, i.e., large-scale flow field and magnetic field, in the stellar interior with a particular emphasis on the supernova core on the ground of comparisons with the Sun.

When the massive star collapsing, the compositional convection is excited almost invariably in the nascent neutron star (called, Proto-Neutron Star: PNS) due to the negative gradient of the lepton fraction induced by neutrino radiations. The convection then reaches the velocity up to O(10^8) cm/sec, resulting in the kinetic energy density of O(10^29) erg/cc with the baryonic density of O(10^13) g/cc typical in the PNS.

Since the MHD approximation is applicable to the nuclear matter of the PNS, it has been expected that the magnetic field is generated and maintained as a natural consequence of the non-linear interaction between the convection and electric current, that is, convective dynamo process (Thompson & Duncan 1992). With a simple energy equipartition argument, the dynamo-generated magnetic field is estimated to have the strength of O(10^15) G, providing a natural explanation of the strongly-magnetized neutron star, called “Magnetar”, which is a rare subclass of the neutron star. However, if it is universal, we can not explain, perversely, the weak magnetization of the ordinary pulsar (~ 10^12 G) which is a sizable subclass of the neutron star. The situation is controversial. “What makes Magnetars different from the other major members ?” That is an important issue in our study.

For solving the mystery in the magnetization process of the neutron star, we are now studying the MHD process in the fully-convective PNS by means of 3D simulation. To deal with whole the PNS from the center to the neutrinosphere, we developed a Cartesian dynamo simulation model (PNS in BOX) and applied it to our modeling. Here we will show our recent results obtained by a series of convective dynamo simulations with a realistic internal structure of the PNS and realistic EOS of the dense and hot nuclear matter. From our study, we found, for the first time, that the mean zonal and meridional flows are spontaneously organized in the PNS. Furthermore, by the convective dynamo process, the strong, large-scale magnetic field with a dipole symmetry (O(10^14) G) is also built up in whole the PNS. We will discuss, in more detail, the generation mechanisms of the large-scale structures of flow and magnetic fields and compare them with those in the Sun in our talk.

Asymmetric magnetic reconnection at the dayside magnetopause

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Since 2015, NASA's Magnetospheric Multiscale (MMS) spacecraft have made electron-scale measurements of reconnection sites in the Earth's magnetosphere (Burch et al. 2016 Science, Torbert et al. 2018 Science). In particular, taking advantage of its orbit, MMS has observed many reconnection events at the dayside magnetopause, where asymmetric-type reconnection occurs between a dense solar-wind plasma and a tenuous plasma that is threaded by the Earth's dipole magnetic field. To support these observations, properties of asymmetric reconnection has been extensively studied by means of particle-in-cell (PIC) simulations in the last decade.

In this talk, we overview our recent studies on asymmetric magnetic reconnection by means of 2-D PIC simulations (Zenitani et al. 2017 JGR [1]). We explore electron-physics signatures near the reconnection site. On the magnetospheric side of the X line, a normal electric field enhances the electron meandering motion from the magnetosheath side. The motion leads to a crescent-shaped component in the electron velocity distribution functions (VDFs), in agreement with MMS observations. On the magnetosheath side of the X line, the magnetic field line is deformed in the third dimension. This makes electron motion chaotic, and then the electron ideal condition is no longer satisfied.

In addition, we have extensively surveyed spatial distributions of ion and electron VDFs near the reconnection site. We have generated approximately 70,000 VDFs for this study. They have been made public at http://rish.kyoto-u.ac.jp/~zenitani/MRA/ in the hope that others may find it useful.

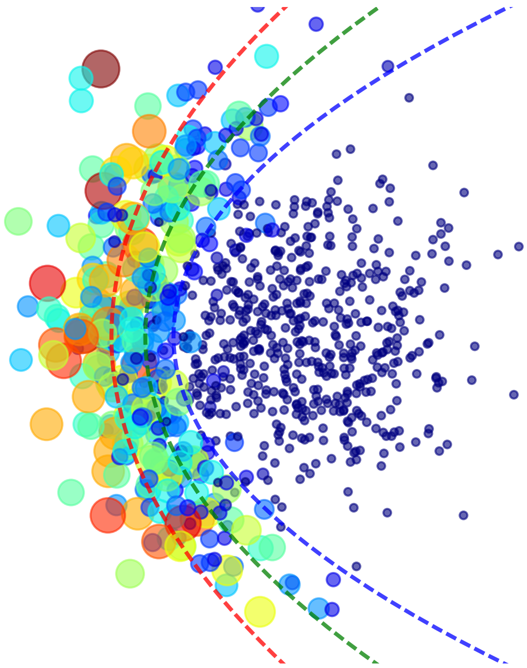

Figure 1: Properties of individual particles in an electron velocity distribution function near the X-line (See Fig. 3 in Ref. [1] for detail)

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Experimental Observation of Electron-scale Turbulence Evolution across the L-H Transition in National Spherical Torus Experiment

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While it is well accepted that the L-H transition is due to the suppression of edge turbulence and thus forming edge transport barrier (ETB), previous turbulence measurements at the L-H transition focused on low-k (ion-scale) turbulence [1]. Electron-scale turbulence has been found to be an important candidate for electron thermal transport in NSTX [2,3]. Thus in order to fully understand the L-H transition physics in NSTX, it is important to understand the role of electron-scale turbulence in the L-H transition. Here we report observations of electron-scale turbulence evolution across the L-H transition for the first time for NSTX. The electron-scale turbulence measurement (for $3 \lesssim k_\perp \rho_s \lesssim 13$) was carried out using a collective microwave scattering system in NBI-heated NSTX plasmas with I_p=0.9/1.1 MA, B_T=5.5 kG and NBI heating power of 2-6 MW. The measurement was made at r/a≈0.71-0.88 and is at smaller radius than the location of the edge transport barrier in the H-mode phase (r/a $\gtrsim$ 0.89-0.9). The electron-scale turbulence is observed to be quasi-stationary before the L-H transition, and an intermittent phase for the electron-scale turbulence is observed after the L-H transition with a gradual decrease in overall turbulence density fluctuation spectral power with intermittent large relative variations (on ~0.5-1 ms time scale) in the total spectral power. A turbulence-quiescent phase is observed following the intermittent phase. A recovery phase is seen after the quiescent phase, where the electron-scale turbulence fluctuation power starts to gradually increase. It is found that the suppression of the electron-scale turbulence is more significant at lower wavenumbers, namely $k_\perp \rho_s \lesssim$8-9. Simultaneous ion-scale turbulence measurements at larger radius than the electron-scale turbulence measurement location show similar temporal behaviour in the ion-scale turbulence as in the measured electron-scale turbulence. These observations demonstrate that the suppression of turbulence during the L-H transition is not just limited to the ETB region. None of the measured electron-scale turbulence and ion-scale turbulence from edge into core is found to be obviously leading in the response to the L-H transition, and the overall turbulence suppression after the L-H transition at different radii seems to start at the same time and is a gradual process happening on a tens-of-ms time scale. The trend of decrease in the electron-scale turbulence during the L-H transition is found to be consistent with the decrease in the maximum ETG linear growth rate from linear gyrokinetic stability analysis. However, the observed intermittency in the electron-scale turbulence during the intermittent phase cannot be explained by the linear analysis.

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Zonal flow generation by potential vorticity mixing in rotating tokamak plasmas

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Zonal flows, the turbulence-driven $E \times B$ flows caused by toroidally and poloidally symmetric electrostatic potential, have a strong influence on turbulence regulation and the subsequent transport reduction in magnetically confined plasmas. Since the main source of the zonal flow generation is the nonlinearity in the perpendicular $E \times B$ drift, the ion parallel compression has not attracted much attention in relation to the zonal flow generation process. Recently, some previous studies have shown that zonal flows may actually be driven by the parallel compression [1,2].

To uncover role of the parallel compression in zonal flow generation, we perform a potential vorticity (PV) transport analysis of gyrokinetic simulations of toroidal ion temperature gradient-driven turbulence. In this work, we employ the kinetic version of the PV mixing theory [3] to make an in-depth analysis of the zonal flow generation mechanism.

We show that the generation of zonal flow is explained by the PV flux. In the absence of equilibrium rotations, the two dominant contributions to the PV flux come from the parallel compression and the grad-*B* drift, which largely cancel out each other. With an equilibrium parallel rotation shear, however, the parallel compression-driven flux dominates the grad-*B* drift-induced one, resulting in a strong net PV flux. Consequently, zonal flow is amplified and turbulence fluctuation level decreases as compared to the non-rotating plasma. Our findings manifest that the parallel compression has a strong influence on the zonal flow generation and confinement improvement for rotating tokamak plasmas.

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Energetic particle transport induced by wave-particle interactions in a torus plasma

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In fusion burning plasmas, which will be realized in future, the plasma is heated by energetic alpha particles produced by deuterium-tritium fusion reactions in the plasma. Therefore, the good confinement characteristics in the torus are required for energetic particles as well as thermal plasma. The energetic particles loose the energy mainly due to the collision process with the thermal plasmas, which is the process of bulk plasma heating (alpha heating). The velocity distribution function of the energetic particles produced by the collisions has a negative slope ($\partial f_{\mathrm{EP}}/\partial v < 0$) in whole energy range. However, Alfven wave may resonate with such energetic particles and become unstable, of which free energy is spatial gradient of energetic particle density. As a result of relaxation of the free energy, the radial transport of energetic ions is induced. In this talk, two experimental studies will be presented, and the comparison with linear and nonlinear models of energetic particle transport will be also discussed.
An experimental study of the energetic particle transport induced by the interaction with Alfven wave in the magnetically confined torus plasma was carried out with a hybrid probe, which can measure simultaneously the local energetic ion flux and the local magnetic fluctuation. The energetic ions were produced by neutral beam injection for plasma heating. Alfven wave with nonlinear properties such as bursting, fast frequency shift etc. was observed to be excited, when the energetic ion pressure becomes comparable to the bulk plasma pressure. It was experimentally found that the energetic ion transport is proportional to the square of wave amplitude and the gradient of the fast ion density [1]. This is a fundamental property of the particle transport induced by wave-particle interaction, and is also common with anomalous transport induced by turbulence.
The energetic ion profile realized with Alfven wave excitation was also experimentally investigated with deuterium plasma experiment in large helical device (LHD) [2]. It was found that the similar energetic ion profile was observed with different beam deposition profiles when Alfven wave was excited. This observation is consistent with profile stiffness of energetic ions, which is considered to be understood by the critical gradient model of energetic ions [3,4].

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Turbulent Dynamo in a Weakly Ionized Medium

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The small-scale turbulent dynamo is an important process contributing to the cosmic magnetization. In partially ionized astrophysical plasmas, the dynamo growth of magnetic energy strongly depends on the coupling state between ions and neutrals and the ion-neutral collisional damping effect. A new damping stage of turbulent dynamo in a weakly ionized medium was theoretically predicted by Xu & Lazarian (2016). By carrying out a 3D two-fluid dynamo simulation, we for the first time numerically confirmed the physical conditions and the linear-in-time growth of magnetic field strength of the damping stage of dynamo. The dynamo-amplified magnetic field has a characteristic length as the damping scale, which increases with time and can reach the injection scale of turbulence after around eight largest eddy-turnover times given sufficiently low ionization fraction and weak initial magnetic field. Due to the weak coupling between ions and neutrals, most turbulent energy carried by neutrals cannot be converted to the magnetic energy, resulting in a relatively weak magnetic field at the end of dynamo. This result has important implications for the growth of magnetic fields in the partially ionized interstellar medium, the first star formation, and the shock acceleration of Galactic cosmic rays.

Plasma Dynamics in Interstellar Molecular Clouds

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In this paper, we give a talk about two topics that have to do with plasma dynamics of molecular clouds in the interstellar medium: one is shock-triggered star formation where MHD physics plays crucial role [1], and another topic is a dynamics of cosmic-ray streaming instability in molecular cloud nearby supernova remnant where the so-called Bell instability plays critical for gamma-ray emission spectrum [2].

Since supersonic turbulence is general in molecular clouds, shock waves propagate ubiquitously in molecular clouds. In this paper, the influence of a shock wave on the evolution of a molecular cloud is studied by using isothermal MHD simulations with the effect of self-gravity [1]. Adaptive-mesh-refinement and sink particle techniques are used to follow long-time evolution of the shocked cloud. We show that the shock compression of turbulent inhomogeneous molecular cloud creates massive filaments, which lie perpendicularly to the background magnetic field. The massive filament shows global collapse along the filament, which feeds a sink particle located at the collapse center. We find that the collapse of the filament is started when the line mass of the filament becomes larger than the critical line-mass of magnetized filament derived analytically by Tomisaka (2014) [3]. This indicates that the critical line-mass of the massive filament is controlled mainly by magnetic field. We observe a high accretion rate $M_{acc} > 10^{-4}$ M_{sun}/yr that is high enough to allow the formation of even O-type stars. The most massive sink particle achieves $M > 50$ M_{sun} in a few times 10^5 yr after the onset of the filament collapse.

Molecular clouds are very important emission site of gamma rays, because cosmic ray accelerated at supernova remnants propagate into a molecular cloud and gamma ray is created when a cosmic-ray proton collide with a hydrogen that composes the molecule cloud [4]. The gamma ray spectrum emitted from the molecular cloud depends strongly on the diffusion coefficient of cosmic rays, and thus depends on turbulent structure of magnetic field in the molecular cloud. Using hybrid simulations of cosmic ray streaming and background MHD, we demonstrate that the streaming of cosmic rays in molecular cloud causes the so-called Bell instability that creates turbulent magnetic field and regulates diffusion coefficient [2]. The resulting gamma ray spectrum from the molecular cloud is found to be consistent with recent observation by Fermi satellite [5].

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Experimental study of reconnection heating/transport process and its application to high temperature spherical tokamak formation

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We present recent progress of our experimental research on reconnection heating using in-situ/ultra-high-resolution 2D imaging diagnostics such as 96CH/320CH 2D ion Doppler tomography and its application to high temperature spherical tokamak formation. As in solar flares, laboratory experiments of magnetic reconnection historically demonstrated high temperature plasma formation such as ΔT_i ~250eV in TS-3 with reconnecting magnetic field B_{rec} < 0.1T and ΔT_i ~ 1keV in MAST with B_{rec} < 0.15T: $\Delta T_i \sim B_{rec}^2$ scaling. Magnetic reconnection heats electrons locally around X-point where current sheet dissipation occurs and ions downstream where kinetic energy of reconnection outflow jet dissipates. When guide field exists (toroidal field B_t in tokamak merging), characteristic scale size such as ion gyro radius ρ_i gets very small in the order of ρ_i < 20mm and reconnection heating profile typically forms fine structure when high guide field is applied. Electron temperature profile becomes more steep distribution around X-point and the maximum peaked temperature increases when higher guide field is applied. Ion temperature profile is also affected and polarity effect of guide field reconnection by Hall term appears around current sheet to form tilted ion temperature profile. Maximum ion temperature typically appears downstream and forms double peak structure at the end of merging. In flux tube merging configuration, those hot spots formed by outflow heating appear on the thick layer of closed flux surfaces of toroidal plasma, perpendicular heat transport is strongly suppressed when high guide field is applied and finally forms *field aligned* hollow structure (while electron temperature keeps the peaked structure around the X-point). Those different temperatures equilibrate in the time scale of ion-electron energy relaxation time and both ion and electron temperature form triple peak distribution after merging during the equilibration process. The application of high power reconnection heating is adopted in the new high field spherical tokamak experiments on TS-6 and ST40, which successfully made first plasma in 2018 and expected to achieve new records in 2019 based on the extension of $\Delta T_i \sim B_{rec}^2$ scaling when high field operation starts. The latest reports from those projects will be presented.

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Predictability of imminent giant solar flares based on the triggered instability model

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Solar flares are catastrophic explosions in the solar corona and may potentially cause a severe space weather disaster which impacts various infrastructures1. Solar flares are widely believed to be driven by the rapid release of magnetic energy stored in solar active regions (ARs) around visible sunspots. Although many models have been proposed, which parameters of the magnetic field determine the occurrence and properties of solar flares has not been completely explained. Therefore, it is still difficult to accurately predict the occurrence of giant solar flares. We developed a new model (called the κ-scheme), which is capable of predicting where giant solar flares may occur and how large they may be from vector magnetic field data on the solar surface based on the new magnetohydrodynamic (MHD) instability model [1]. In this paper, we demonstrate the κ-scheme's ability to predict giant solar flares by analyzing the largest solar flares in solar cycle 24. Here, we show that the distribution of the magnetic twist flux density in the vicinity of the magnetic polarity inversion line (PIL) on the solar surface plays a crucial role in determining not only the sizes of solar flares but also when, where, and how solar flares may occur. The result indicates that the physics-based analysis of stability is a powerful tool to predict imminent giant solar flares.

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A Statistical Study of Slow-Mode Shocks Observed by MMS in the Dayside Magnetopause

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The existence of slow-mode shocks in the magnetic reconnection region has been proposed since 1964 (e.g., [1]; [2]). While, there have been many reports on the observation of slow-mode shocks in the magnetotail region (e.g., [3]; [4]; [5]), there are only two event studies which have reported the presence of slow-mode shocks in the magnetopause reconnection ([6]; [7]). Many MHD simulations of magnetopause reconnection (e.g., [8]; [9]; [10]) have reported the presence of slow-mode shocks and their dependence on the local magnetosphere and magnetosheath parameters. We investigated characteristics of slow-mode shocks in the dayside magnetopause based on MMS observations from September 2015 to February 2017. We analyzed 99 magnetopause crossings with reconnection jets and burst-mode (high time resolution) data, out of which 20 magnetopause crossings were observed to have slow-mode shock signatures. We also found 12 rotational discontinuities in these slow-mode shock crossings. Our results also show that the observation of magnetosphere slow-mode shock is favored when the ratio of the number density of magnetosheath to magnetosphere is small. No clear dependence of existence of slow-mode shocks on other parameters such as, plasma beta, temperature anisotropy, jet velocity was found.

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Global Three-dimensional Radiation MagnetoHydroDynamic Simulations of the Time Variabilities of X-ray Emitting Region in Seyfert Galaxies

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High energy emissions and jet ejections are observed from Active Galactic Nuclei (AGN) are believed to be driven by mass accretion onto a Super Massive Black Hole (SMBH). Since the temperature of the optically thick accretion disk in Seyfert galaxies is the order of 10^5 K, Ultra Violate (UV) radiation is dominant. We should consider either jets, hot disk corona, or optically thin disks to explain the hard X-ray emission observed in Seyfert galaxies. Noda et al. (2016,2018 [1],[2]) found that when the X-rays luminosity of Seyfert galaxies increase, highly variable soft X-ray excess region appears. Such regions can be formed by cooling of the hot hard X-ray emitting accretion flows.

To study the cooling of the hot accretion flow in Seyfert galaxies, we applied Radiation MagnetoHydroDynamic code CANS+R (Takahashi & Ohsuga 2013,2016 [3],[4]) based on M1-closure scheme to accretion flows around a $10^7\ M_{\odot}$ black hole. We found that when the accretion rate is 10% of the Eddington accretion rate ($\dot{M}_{\mathrm{Edd}}$ corresponding to the Eddington luminosity), hot accretion flows ($\sim 10^{11}$ K) inside 10 Schwarzschild radius from black hole co-exists with the outer cool ($10^6 - 10^7$ K) disk dominated by radiation pressure. Furthermore, it was found that the intermediate region between the hot accretion flow and the cool disk oscillates quasi-periodically with the time scale of the rotation period of this region. The intermediate region can be the soft X-ray excess region observed during the brightening of Seyfert galaxies.

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Stochastic Shock Drift Acceleration Model with Finite Pitch-Angle Anisotropy

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The acceleration of non-thermal electrons is one of the important subjects in space physics. The shock accelerated non-thermal electrons have been observed at Earth's bow shock [1]. 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 Earth's bow shock found wave-particle interactions between whistler waves and electrons at the shock transition region [2]. These results indicate that whistler waves play an important role for the acceleration of supra-thermal electrons.

We propose the stochastic shock drift acceleration (SSDA) model as a new acceleration mechanism for supra-thermal electrons [3]. It takes into account the effect of stochastic pitch-angle scatterings by whistler waves during the course of the Shock Drift Accelerations (SDA), which is a classical acceleration model for supra-thermal electrons at the shock transition region [4][5]. By introducing stochasticity with pitch-angle scatterings, the acceleration efficiency may be improved.

We theoretically analyzed this acceleration model. We showed that the electron energy spectrum becomes a power-law consistent with observations in the limit of strong scatterings. We also found the cutoff-energy of the proposed model, and it scales linearly with the pitch-angle scattering coefficient which represents the strength of scatterings.

In our previous study, the SSDA model assumes an isotropic electron pitch-angle distribution. However, finite anisotropy of the electron pitch-angle distribution emerges especially near the cut-off energy, we cannot apply our model near this region. To discuss the electron distribution near the cut-off energy, we need to modify our SSDA model to take into account finite anisotropy.

In this study, we extend our model so that the dependence of space and pitch-angle can be considered. We numerically solved the electron transport equation, and discuss consistency between the previous and current model. We also discuss the energy dependence of electron's distribution function near the cut-off energy.

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Origin of Cosmic Ray Electrons and Positrons

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With experimental results of AMS on the spectra of cosmic ray (CR) e^-, e^+, $e^- + e^+$ and positron fraction, as well as new measurements of CR $e^- + e^+$ flux by HESS, one can better understand the CR lepton (e^- and e^+) spectra and the puzzling electron-positron excess above ∼10 GeV. In this article, spectra of CR e^- and e^+ are fitted with a physically motivated simple model, and their injection spectra are obtained with a one-dimensional propagation model including the diffusion and energy loss processes. Our results show that the electron-positron excess can be attributed to uniformly distributed sources that continuously inject into the galactic disk electron-positron with a power-law spectrum cutting off near 1 TeV and a triple power-law model is needed to fit the primary CR electron spectrum. The lower energy spectral break can be attributed to propagation effects giving rise to a broken power-law injection spectrum of primary CR electrons with a spectral hardening above ∼40 GeV.

Our work has been published by MNRAS recently, please refer to our article [1] for more details.

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Nonlinear simulation of energetic particle driven geodesic acoustic mode channeling using MEGA code

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In the LHD experiment, anomalous bulk ion heating during the energetic particle driven geodesic acoustic mode (EGAM) activity suggests an energy channel created by EGAM[1]. The phenomenon of EGAM channeling has direct significance for plasma heating efficiency. A hybrid simulation code for energetic particles (EPs) interacting with a magnetohydrodynamic (MHD) fluid, MEGA[2], is used for the simulation of EGAM. Both the bulk ions and EPs are described kinetically.

A global electrostatic mode is reproduced in the simulation, and the simulated mode is identified as an EGAM. Both the mode number and the mode frequency are consistent with the theoretical predictions. The ions obtain energy when the energetic particles lose energy during the EGAM activity, and this indicates that an energy channel is established by EGAM. The EGAM channeling is reproduced by simulation with realistic parameters for the first time[3]. From $t = 0$ to $t = 0.36$ ms, the heating power to bulk ions is 3.4 kW/m^3. In order to identify the dominant resonant particles, the energy transfer rates of bulk ions at different times are analyzed in the particle transit frequency space. There is a peak around $f = 25$ kHz which is the half of mode frequency appears in the phase space, and the frequency of this peak gradually increases. This frequency increase indicates that these bulk ions are kept resonant with the mode. The resonance condition $f_{EGAM} = l \cdot f_{tr,bulk}$ is satisfied where the dominant l value is $l = 2$. In addition, another peak appears around $f = 15$ kHz in the phase space. In this simulation, the bulk ion temperature $T_i = 4.85$ keV, and this thermal velocity corresponds to a transit frequency 14.7 kHz. The lower peak around $f = 15$ kHz appears in the phase space because most bulk ions' transit frequencies are around 15 kHz.

In addition to the mechanism, other properties of EGAM channeling are also systematically investigated with realistic parameters for the first time. For example, the bulk ion heating power increases with the EGAM amplitude, because stronger mode activity transfers more energy to the bulk ions. But the energy transfer efficiency (E_{ion}/E_{EP}) is not sensitive to the EGAM amplitude, because both the energy absorption of bulk ions and the energy loss of energetic particles change together. Furthermore, lower frequency EGAMs make higher energy transfer efficiency, because the interactions between lower frequency mode and bulk ions are stronger.

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Ion versus electron heating in astrophysical gyrokinetic turbulence

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Many astrophysical plasmas are weakly collisional, meaning that ions and electrons can have different temperatures. What is the key mechanism that sets the difference in the temperatures between the species? This is a crucial problem for understanding far-distant astronomical objects. For example, the ion-to-electron temperature ratio is a key *unknown* parameter for interpreting the black hole image observed by the Event Horizon Telescope Collaboration [1]. In this study, we aim to determine the partitioning of heating between ions and electrons by focusing on the dissipation of weakly collisional turbulence.

We numerically solved the Alfvénically driven turbulence using the gyrokinetic-ion and isothermal-electron-fluid hybrid model [2,3]. The result shows that the ion-to-electron heating ratio $Q_\mathrm{i}/Q_\mathrm{e}$ is an increasing function of ion beta β_i except for the upper bound ($Q_\mathrm{i}/Q_\mathrm{e} \sim 30$) at $\beta_\mathrm{i} \gtrsim 10$ [4]. At very low β_i, most of the Alfvénic driving power is converted to electron heating, which is consistent with a theoretical prediction [5]. We also found that $Q_\mathrm{i}/Q_\mathrm{e}$ is insensitive to the background ion-to-electron temperature ratio $T_\mathrm{i}/T_\mathrm{e}$. This tendency indicates that a weakly collisional plasma heated by turbulence prefers a two-temperature state where ions are hotter than electrons unless β_i is extremely small. The simulation also produced an interesting by-product: magnetically dominated spectra in the ion kinetic scale at high β_i, which is akin to the high Pm MHD spectra in the inertial range [6].

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Fast ion driven drift instability in reversed shear plasmas

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It is shown that fast ions can be destabilize the electron drift wave because fast ion reverse their precession direction in RS plasmas to electron diamagnetic direction and can resonate with electron drift wave [1]. A local stability analysis of this new instability is performed and consequent quasi-linear transport is calculated using gyrokinetic equations in toroidal geometry [2,3], under fusion reactor condition. The new instability occurs when the temperature gradient of fast ions peaks sufficiently compared to the density profile and the linear growth rate is linearly proportional to the temperature gradient length of fast ions which is the free energy source of the instability. The resulting quasi-linear particle flux of fast ions is outward while the particle flux of main hydrogenic ions is inward. These results show that the new instability might be beneficial for burning plasma operation because it can expel lower energy He ions preferentially while keeping the ion working gas inside.

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Influence of Energetic Ions on Residual Zonal Flow

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Zonal flows are well known to regulate and reduce tokamak plasma turbulence and transport. A noteworthy property of zonal flows in toroidal plasma is that it is damped to non-zero amplitude, known as residual zonal flow level, in the absence of collisional and turbulence-induced damping. Since Rosenbluth and Hinton analyzed residual zonal flow level in the long wavelength regime ($k_r\rho_{i,b} \ll 1$, $\rho_{i,b}$ is banana orbit width) [1], there have been various extensions which mostly assumed Maxwellian equilibrium distribution for every ion species. However, for fusion product α-particles in tokamak plasmas, the Maxwellian distribution is a poor approximation and the slowing-down distribution should be used. For those reasons, we investigate the residual zonal flow in the presence of energetic ions with slowing down distribution using the modern gyrokinetic approach in the electrostatic limit. The residual zonal flow is predicted to be enhanced considerably for ITER plasmas in the radial wave-number regime of $k_r\rho_{i,eff} \sim 10^{-1}$, where $\rho_{i,eff}$ is the Larmor radius of a thermal ion of background plasma consisting of Deuterium and Tritium. This is a consequence of the fact that larger Larmor of an energetic α-particle lead to an enhancement (a reduction) of the classical (neoclassical) polarizability at that wave-number regime compared to the case without α-particles. This enhancement is slightly more pronounced for the slowing-down distribution compared to the Maxwellian if $T_e \gtrsim 20keV$ for $E_\alpha = 3.5MeV$. In addition, we find that the Rosenbluth-Hinton formula for the residual zonal flow level that has been derived for the Maxwellian equilibrium ion distribution remains valid in the long wavelength and high aspect ratio limit for any well-behaved ion distribution function which is isotropic in velocity space [2].

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Subgrid-scale modeling based on Mori-Zwanzig formalism

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Direct numerical simulations (DNS) of plasma turbulence with utilizing massively parallelized supercomputers promote the understanding of multi-scale nature of plasma turbulence. Recent multi-scale plasma turbulence researches revealed the existence of cross-scale interactions between short-wavelength electron-scale turbulence and long-wavelength ion-scale turbulence in magnetically confined plasmas [1,2,3]. Although more case studies are demanded for clarifying the condition of cross-scale interactions, the number of analyses is limited so far because of its extremely high computational cost. Therefore, in anticipation of understanding the generic features and of constructing a reduced simulation model of multi-scale turbulence, we discuss the methodology for extracting and modeling the contributions from small-scale fluctuations on large-scale fluctuations.

Mori-Zwanzig projection operator method [4], which has been developed in non-equilibrium statistical physics researches, describes the governing equation of variables in the form of generalized Langevin equation. In other words, in equation for variables of interests, contributions from the other variables are extracted as the memory function and the noise term. Applying the projection operator method for dividing the system into large-scale fluctuations (= variables of interests) and small-scale fluctuations (= the other variables), one expects to extract and model the small-scale contributions on large-scale fluctuations.

As an example, we examined the applicability of the Mori-Zwanzig projection operator method to the Kuramoto-Sivashinsky equation, which is a simple example of non-equilibrium open system of one-dimensional turbulence. We evaluated the memory functions and the noise term from the DNS data of Kuramoto-Sivasinsky turbulence. Then we confirmed that the generalized fluctuation-dissipation theorem of the second kind, which states the relation between the memory function and the time-correlation of the noise term, was numerically satisfied. Additionally, using the memory function and the noise term obtained from DNS data, we constructed a reduced model for large-scale fluctuations including small-scale contributions. It was demonstrated that such a subgrid-scale modeling reproduces the energy spectrum same as the DNS of Kuramoto-Sivasinsky turbulence.

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Molecular clouds associated with magnetic features in the Galactic Center

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I will talk about properties of molecular clouds associated with magnetic flotation loops and the double helix nebula (DHN). The magnetic field plays an important role in the formation and the evolution of molecular clouds. The Galactic Center (GC) contains huge amount of molecular gas, which reaches ∼10 % of that of the MilkyWay. In this region, the magnetic field is frozen into the gas and hence, the typical strength of the magnetic field of 50 μG is one order of magnitude higher than that of the Galactic disk region. Fukui et al (2006) [1] discovered molecular loops 1 and 2 in the GC and they proposed a magnetic flotation model like solar prominences. Recently we investigated the common foot point of loop 1 and 2, and discovered evidence for cloud-cloud collisions. We found that the collisions enlarges the inner velocity dispersion of colliding clouds. The loop induced cloud collision model possibly explain the long-time mystery of large velocity dispersions seen in the GC clouds (Enokiya et al. 2019 submitted). The latter half I will briefly introduce another magnetic structure, the DHN[2]. The DHN showing the spectacular helical shape in mid-infrared is located ∼100 pc above Sgr A* with strong magnetic field along with the helices and suggested to be a torsional Alfven wave twining a jet launched by the circumnuclear disk (CND). Our previous CO observations discovered a huge 100 pc molecular tower extended from the CND to the DHN[3]. Recently we observed the DHN in CO (J=1–0 and 3–2). From this observations, we found possible triggered star formation activities; the small (1–2 pc) elongated dense CO clumps with ∼1000 solar masses are stuck perpendicular to the direction of the magnetic field lines. This implies a possibility that the magnetic outflow triggers the star formation.

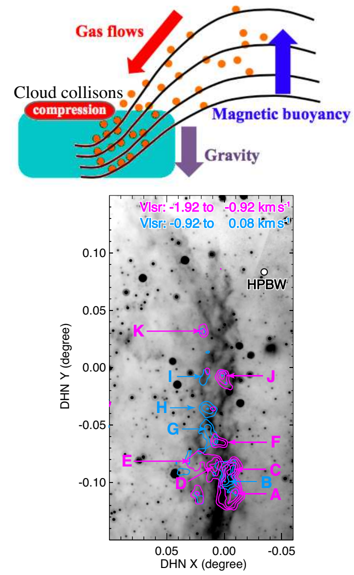

Figure 1: *Top* Schematic image of the loop-induced cloud collision model. *Bottom* The distribution of CO clumps associated with the DHN.

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Electron Pre-acceleration at Shocks in High-beta Plasmas of Galaxy Clusters

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Radio relics in the outskirts of galaxy clusters have been observed and are interpreted as synchrotron emission from relativistic electrons produced via diffusive shock acceleration (DSA) in weak shocks ($M_s < 3.0$). DSA theory states that the particle momentum should be greater than a few times the momentum of thermal protons to cross the shock transition and participate in the Fermi acceleration process. In thermal equilibrium, the momentum of thermal electrons is much smaller than that of thermal protons, so electrons need to be pre-accelerated before they can participate in DSA. To understand such electron injection process, we study the electron pre-acceleration at weak quasi-perpendicular shocks (M_s = 2.0 - 3.0) in high beta plasmas of the intracluster medium, by performing 2D particle-in-cell (PIC) simulations [2]. A previous PIC simulation study [1] found that in quasi-perpendicular shocks, a substantial fraction of electrons are reflected upstream, gain energy via shock drift acceleration (SDA), and generate oblique waves via the electron firehose instability (EFI), leading the energization of electrons through wave-particle interactions. We find that such kinetic processes are effective only in supercritical shocks with M_s above a critical Mach number, $M_s^* \sim 2.3$. In addition, even in shocks with $M_s > 2.3$, energized electrons may not reach high energies to be injected to DSA, because the oblique EFI alone fails to generate long-wavelength waves. Our results should have implications for the nature of radio relics in galaxy clusters.

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Synthetic Ultraviolet Emissions from Coronal Loops Supporting Fast Sausage Modes

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Forward modeling the emission properties in ultraviolet (UV) passband is important for confidently identifying magnetohydrodynamic waves using the modern imaging and spectroscopy instruments in the structured solar corona. In this work, we examine the UV emissions from sausage modes supported by a straight magnetic tube. We incorporate non-equilibrium ionization into the computation of the emissivity, taking the Fe IX 171 Å and Fe XII 193 Å lines as examples. We find that non-equilibrium ionization effects can considerably change the line intensity while have little effects on the Doppler width or Doppler velocity. Using the spatial and spectral resolutions of IRIS, we then forward model the Fe XXI 1354 Å line of sausage modes in flare loops and examine their observational signatures. Our results are largely consistent with a recent IRIS observations of sausage modes in flare loops. Our work is helpful to identify sausage modes in solar corona using the modern instruments.

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Formation of Virtual Anode and potential well along with its fluctuation characteristics in presence of plasma bubbles in unmagnetized and magnetized plasma

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The report is intended to investigate the experimental evidence of virtual anode and potential well structure and its associated nonlinear behavior of plasma bubble (PB) in filamentary discharge unmagnified and magnetized plasma. Plasma bubbles are created in bulk plasma by a negatively biased spherical mesh grid of almost 80% transparency. Argon plasma is produced in the cylindrical chamber of dimension 350 mm in length and 400 mm in diameter. Plasma bubble is the plasma volume of spherical shape of 120 mm diameter separated from the bulk plasma. The chamber is evacuated down to 1.9×10^{-5} mbar using both diffusion and rotary pump. Ar gas is injected by a needle valve into the chamber at working pressure of 1.4×10^{-4} mbar. The spherical mesh grid can congregate the particles from the plasma radially when it is biased negatively. In case of unmagnetized plasma, a virtual anode structure has been formed around the bubble when all electrons are reflected. When introducing magnetic field, a potential well type structure has been observed inside plasma bubble. A radially movable electrical Langmuir probe and hot emissive probe are used to measure basic plasma parameters. The sheath instability inside the bubble has been observed and there appears a regime of quasiperiodicity with various frequencies, which are the frequencies of instability and the external electric field. While scanning the bubble at different positions leads routes to chaos through periodic doubling from the quasiperiodic regime. In order to demonstrate the chaos observed in experiments, characteristics of chaos such as Lyapunov exponent is acquired using an experimental time series. The experimentally observed ion sheath oscillations are confirmed by numerical modelling along with the predicted theory.

A change of parity at the MHD collapse event of tongue in magnetically confined laboratory plasma

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A change of parity of plasma displacement is observed in the energetic particle driven MHD collapse with non-resonant tongue-shaped deformation in magnetically confined laboratory plasma [1-3]. There are three states 1) stationary 1/1 resonant mode with interchange parity, 2) tongue-shaped deformation of non-rational surface, and 3) rotating 1/1 resonant mode with tearing parity in the discharge with MHD bursts. The quasi-stable stationary 1/1 MHD mode with interchange parity appears near the resonant rational surface of q = 1 between MHD bursts. The tongue event, which is characterized by the rapid increase of plasma displacement localized at the non-resonant (non-rational) surface. It curbs the stationary 1/1 MHD mode then triggers the collapse of energetic particle and magnetic led reconnection. The rotating 1/1 MHD mode with tearing parity at the q = 1 resonant surface, namely MHD burst, is excited after the tongue event. The tongue-shaped deformation triggers the collapse of energetic ion detected by the sharp increase of RF intensity. The MHD burst, characterized by the rotating m/n=1/1 mode, starts 40μ s after (not before) the collapse of energetic ion, which shows that the MHD burst is not the cause but the result of collapse of energetic ion. The result presented in this talk makes a paradigm shift from the conventional view, in which a resonant MHD mode grows and causes the collapse to a new view of the trigger problem. The observation shows that the non-resonant tongue-shaped deformation curbs the resonant MHD mode and trigger the collapse and magnetic field reconnection. This result should have a strong impact on the so-called trigger problem of MHD event in magnetically conned and astrophysical plasmas.

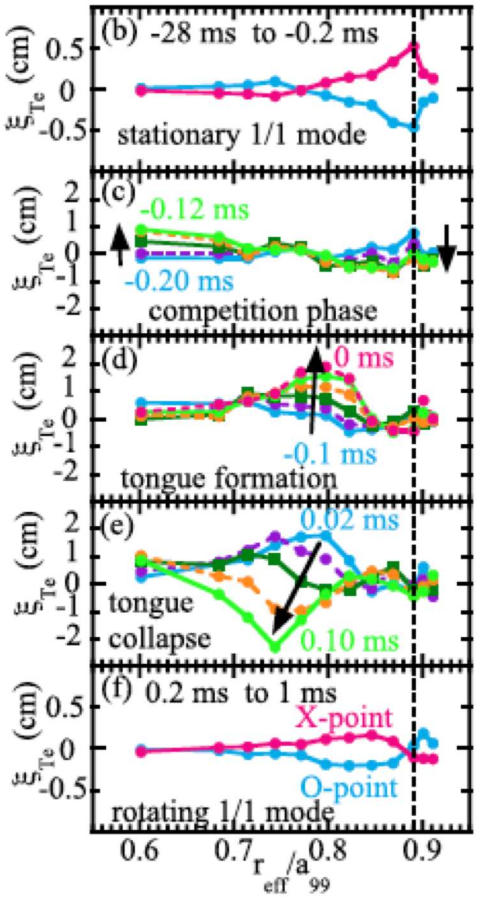

Fig.1 Radial profiles of plasma displacement in phase of stationary 1/1 MHD mode, competition of 1/1 mode and tongue, tongue deformation, tongue collapse, rotating 1/1 MHD mode afterwards [2]. The vertical dashed line indicates the location of the esonant position.

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Wave Physics Computations in Helicon Plasmas

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To reveal the mysterious and still controversial mechanism of high ionization efficiency during helicon discharge, computations on wave physics and instability in various helicon plasmas were carried out and will be presented. These include the resistive drift mode driven by density gradient in WOMBAT (Waves On Magnetized Beams And Turbulence),[1] wave propagation and energy distribution in pinched plasma of MAGPIE (MAGnetized Plasma Interaction Experiment),[2] coupling of RF antennas to large volume helicon plasma,[3] and the effect of first- and second-order radial density gradients on wave field and power absorption.[4, 5] The recent simulation results about the efficient generation of helicon plasma in HPPX (Heating Physics Prototype eXperiment) may be also presented.

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Electron cross-field drift by an induced electric-field in Hall thrusters: from plasma density and potential correlation

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Hall thrusters is one of electric space propulsion machines, and its plasmas can be categorized as the E×B plasmas, having radial B and axial E, see Fig. 1(a). The typical ranges of plasma parameters are, $T_{\mathrm{e}} \sim 20$ eV, $n_{\mathrm{n}} \sim 10^{17}$ - 10^{19} m^{-3}, and $n_{\mathrm{e}} \sim 1$ - 10×10^{17} m^{-3}. Electron cross-field transport in the thrusters has been one of core research interests due to its relation to thruster efficiency. Among several transport mechanisms, azimuthal plasma fluctuation has been proposed as one of possible main contributors. Such transport is similar to the turbulent transport resulting from the phase relation between plasma density and plasma potential observed in various plasma fields.

Regarding the azimuthal fluctuations in Hall thrusters, the E×B drift instability [1] in microscopic scale (mm / over MHz), and the rotating spokes [2] in macroscopic scales (cm / up to kHz) have been known to contribute on the electron cross-field transport. Even though the causes of fluctuations are different, the transport mechanisms are physically analogous in a context of the correlation between the plasma density and the induced electric-field, thus $\langle n_{\mathrm{e}} E_{\theta} \rangle / B$. In this study, by artificially applying azimuthal neutrals inhomogeneity, steady azimuthal E-field is induced, and plasmas properties on $z - \theta$ plane is investigated. The cross-field transport from the macroscopic equilibrium distribution of n_{e} and V_{p} (eg. as in Fig. 1(b)) is studied.

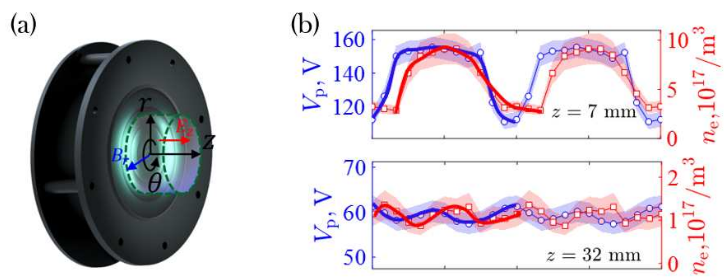

Figure 1: (a) Schematic of the coordinate system of a Hall thruster. Externally applied magnetic field and electric field are shown. (b) Azimuthal distribution of plasma potential and density at z = 7 mm and 32 mm.

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Multi-cusp Plasma Device (MPD) for confining contact ionized alkali ions: source for the experimental studies

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The confinement by multi-cusp magnetic field configuration is being revisited in prospect of developing a Negative Ion Beam source for heating the plasma in fusion devices. For this, an experimental device namely the Multi-cusp Plasma Device (MPD), has been constructed to study the physics of plasma confinement in a multi-cusp configuration. In this experiment alkali ions of low ionization potential will be produced by contact ionization and will be confined in the multi-cusp magnetic field configuration. The cesium ions will be produce by impinging a collimated neutral cesium atoms on an ionizer consisting of a hot tungsten plate. The temperature of the tungsten plate will be made high enough (~2700ºK) such that it will also be contributing electrons to plasma. Hence the design of hot plate ionizer is very crucial. For heating the tungsten plate hot cathode technique will be used. Thermionic electron emission from tungsten plate is exponentially proportional to the temperature of the plate. A gradient of very little value in the temperature of the hotplate, might cause a large temperature gradient and hence large potential difference in plasma which will result in drift thus affecting the experiment. So it is desired to keep the hot plate temperature to be uniform within 1%. The tungsten plate is so hot that the direct contact method for the temperature measurements can't be used. To measure the thermal contours of the ionizer hot plate non-contact method will be used and characterized.

Measurement of high frequency fluctuations in Langmuir wave supercontinuum phenomenon

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Supercontinuum (SC) is a spectral broadening phenomenon which results from nonlinear interaction of seed waves to with the optical medium, such as four-wave mixings, Raman scatterings, etc. Langmuir wave (LW) is an electrostatic wave in plasma and is considered to generate SC because of its unstable nature for modulational instability. We have initiated a demonstration experiment of Langmuir wave supercontinuum (LWSC) in our MPX plasma device. One of our targets in this experimental study is to detect spectral broadening of perturbations of the electron density and the electrostatic potential of propagating LWs. Although simple monopole antennas have been utilized for the purpose in the present experiments, actual physical quantities measured by the method is unclear. Therefore, novel techniques to measure perturbations of the electron density and the electrostatic potential in the LW time and spatial scales is required. In addition to the results of the monopole antenna measurement, we show preliminary results of microwave interferometer using direct conversion as a candidate of the solutions in the poster presentation.

Experimental Demonstration of Langmuir Wave Supercontinuum Generation in Laboratory Plasma

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A spectrum broadening of the initial pump wave owing to nonlinear interaction between the pump wave and medium called supercontinuum (SC) has been observed in various fields, such as optics, hydrodynamics and, plasmas. There exist some applications of SC lights including optical coherence tomography. It is well known that Langmuir waves (LWs) having finite amplitudes in plasmas are described by the nonlinear in plasmas are described by the nonlinear Schrödinger equation, which is considered as a governing equation of various SC phenomena. A preceding study using a particle-in-cell simulation exhibits generation of Langmuir wave supercontinuum (LWSC) [1]. This study targets experimental demonstrations of generation of LWSC in laboratory magnetized plsamas. In experiment, we applied background magnetic fields to realize a one-dimensional configuration wwhich is preferred condition for simplifying the phtsical interpretation of the results. In the preliminary experiment, spectral broadening of electrostatic waves excited by matek grids connected to a high frequency oscillator was observed at the downstream along the magnetic field. We will report the experimental set up the results in detail in presentation.

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Experimental verification of entropy cascade in gyro-kinetic turbulence by velocity space measurement

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This experimental research is aimed at verification of the entropy cascade in gyro-kinetic turbulence by direct measurement of ring-averaged velocity distribution functions of ions. Gyro-kinetic turbulence is a magnetized plasma turbulence whose length and time scales of potential fluctuations are at scales of sub-ion gyro-radius and sub-ion cyclotron frequency [1]. The entropy cascade is induced by nonlinear phase mixing [2] and considered universal in gyrokinetic turbulence as the energy cascade described by the Kolmogorov's law in three-dimension turbulence. The entropy cascade was confirmed by a numerical gyrokinetic simulation [3] and a laboratory plasma experiment by measurement of the wavenumber spectra of electrostatic potential fluctuations at sub-Larmor scales [4]. Our new challenge is an attempt at direct measurement of velocity-space spectra of the ring-averaged ion distribution functions at sub-Larmor scales, which is a key to verify the entropy cascade [3]. The measurement of ring-averaged distribution functions is achieved by the ring-averaged ion distribution function probe (RIDFP), which detects components of the ion current having different velocities via selection of their gyro-radii [5]. In the presentation, we first show observations showing clear transition from coherent drift waves to gyro-kinetic turbulent states dominated by drift waves in our target plasma, MPX plasma. Next we show preliminary results of measurement of equilibrium and fluctuation parts of the ring-averaged ion distribution functions. The velocity-space spectra of the ring-averaged ion distribution functions might be reported depending on the progress of the experiment.

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Study of plasma state in a versatile multi-pole cusp magnetic field

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Multi-pole line-cusp magnetic field configuration can confine dense and uniform plasma in a large volume compared to other peer configurations. Because of these properties cusp confined plasmas have found wide applications viz. basic plasma studies, plasma ion thrusters, ion sources etc. But the optimization of the configuration needs more fundamental studies. In this line, a new multi-pole line cusp configured plasma device (MPD) consisting of six electromagnets has been constructed with versatile magnetic field options [1]. In this device, filamentary plasma has been produced using argon gas to study the basic characteristics. It is expected that, in this set up the desired gradients in the plasma density and temperature can be obtained by varying the current in the magnets. Basic characterisation of the argon plasma thus produced has been completed. A reasonable volume of quiescent plasma has been identified in the centre surrounded by a slightly agitating (fluctuating) plasma at the edge region. The cusp leak-width has been calculated for MPD for different magnetic field values and has been verified with the already published results. The particle confinement estimated from the after-glow plasma is found to be increasing with magnetic field. The profiles of the plasma parameters have been measured using electrical probe diagnostic. The variation in the density and potential fluctuations with respect to the magnetic field have been studied in detail [2]. The fluctuations in the edge region are found to be originating from density gradient driven drift wave instabilities. This has been verified by studying the scale length of plasma parameters, frequency spectra, cross-correlation functions, and their normalized fluctuation levels [3].

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Eigenmode Analysis of the Fast Ion Driven Drift Instability in Reversed Shear Plasmas

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Recently, it has been shown that fast ions in reversed shear burning plasmas can destabilize electron drift wave and its linear growth rate has been calculated in a local stability analysis [1]. We extend the local stability analysis and solve eigenmode equation in ballooning space by including linear toroidal coupling of neighboring poloidal harmonics to treat trapped fast ion response. We calculate eigenmode structure and growth rate using WKB method and shooting method. We also evaluate the stabilizing effect of trapped electron's drift wave precession resonance and compare it with this instability's growth rate. WKB method is more simple and fast compared to shooting method in our analysis, but it is only accurate in low temperature and high safety factor case. The linear growth rate increase with density gradient length of fast ions, as expected in the local analysis. Trapped electron's precession resonance stabilize the drift wave instability in low fast ion fraction.

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Modeling of high-beta plasma equilibria in RT-1 by anisotropic-pressure MHD model

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The Ring Trap 1(RT-1) plasma system realizes a laboratory magnetosphere by magnetically levitating a superconducting ring coil. We are motivated by a high-beta and self-organized plasma in planetary magnetospheres, where the satellites explored. The RT-1 plasma experiments are suitable for elucidation of these physical mechanisms by parameter survey with detail diagnostics, and are also enable us to study an advanced fusion device with inherent characteristics.

In the RT-1, it has been reported that the theoretical approach for self-organization [1] and that the produced plasma achieved the stable high-beta state experimentally with the local electron beta more than 1 [2]. The beta value was evaluated from a relation between the changes in the magnetic flux measured by diamagnetic loops and the plasma equilibrium calculation based on Grad-Shafranov equation. However, it is not clear how the internal plasma profile affects the diamagnetic loop signal.

In this research, firstly we investigate the dependence of magnetic loop signals on plasma pressure profiles with a high-beta state as well as on pressure anisotropy and coexistence of high and low energy electrons observed by x-ray measurement in the RT-1. To analyze these experiments, MHD equilibrium for the dipole plasma is solved numerically [3]. The characterization enhances the understanding of the internal structures from measured magnetic signals. Secondly, by clarifying the relation between plasma pressure profile and plasma diamagnetic signal through the simulation, we discuss the method that identifies the plasma pressure profile more accurately from magnetic measurements. From the optimization, we determine the appropriate arrangement of magnetic measurement in the RT-1.

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Gyrokinetic Simulations for Turbulent Particle Transport of Multi-Species Plasmas in Toroidal Systems

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In order to understand the turbulent transport phenomena of magnetic confinement plasmas in tokamaks and stellarators, we have to consider the effects of multi-particle-species of the plasmas. Especially, the particle transport is strongly affected by the multi-species effects under the ambi-polar conditions between each species. For the transport phenomena, large-scale numerical simulations based on the gyrokinetic frameworks are extremely powerful. Indeed, the gyrokinetic simulation results could be validated against the experimental results of the plasma temperature and density profiles within the observation errors [1].

In this work, we perform the gyrokinetic simulations of the turbulent particle transport phenomena of multi-species plasmas including electrons, hydrogen ions, helium ions, and carbon impurity ions in toroidally magnetic confinement systems. The simulation results for wide ranges of the plasma temperature and density gradients show that the turbulent particle transport fluxes for each species have significantly complicated dependences of the radial gradients of the plasma temperatures and densities with holding the ambi-polar conditions between each species [2]. Furthermore, the remarkable property of the particle transport is found that the turbulent particle fluxes for each species have obvious balance relations with specific species, i.e., the fluxes of hydrogen and helium, and the fluxes of electrons and carbon are separately balanced.

This work is supported in part by JSPS KAKENHI (18H01202 and 19H01879), by NIFS Collaborative Research Program (KNST145 and KNTT050), and by the FLAGSHIP2020, MEXT within the priority study 6. The results are obtained by using K computer at the RIKEN (hp180200 and hp180083), JFRS-1 at IFERC-CSC (KML3D and GDKTHEL), and "Plasma Simulator" at NIFS.

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Excitation and propagation of waves in ion cyclotron harmonics and lower hybrid wave frequency range originated from high energy and low pitch angle ions in a magnetically confined fusion oriented device

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Discrete stair-like frequency radiations in 4th, 5th, 6th, and 7th ion cyclotron harmonic frequencies are observed in series as the lower hybrid frequency reaches 4th, 5th, 6th, and 7th ion cyclotron harmonic frequencies with increase of the plasma density, in a magnetically confined fusion oriented device named the Large Helical Device (LHD). High energy neutral hydrogen beams of 180 keV almost parallel to the external magnetic field and electromagnetic waves in 1st and 2nd electron cyclotron frequencies are injected almost simultaneously for initiation and sustainment of the plasma. High energy and low pitch angle hydrogen ions can exist in weak collision regime [1].
In the previous simulation study with using a one-dimensional electromagnetic particle-in-cell (PIC) code which simulates self-consistently the full ion and electron dynamics, destabilizations of ion cyclotron harmonic waves propagating almost perpendicular to the external magnetic field can occur with existence of energetic ions when the lower hybrid frequency is close to the ion cyclotron harmonic frequency ($\omega \simeq l\Omega_{ci} \simeq \omega_{LH}$) and couple with bulk-ion Bernstein waves [2]. Here, ω is the wave angular frequency, Ω_{ci} is the proton ion cyclotron angular frequency, and ω_{LH} is the lower hybrid angular frequency.
The bulk-ion Bernstein waves can be linearly mode converted to the magnetosonic wave in the plasma core region where the lower hybrid resonance and ion cyclotron harmonic resonance coincide with each other and can propagate toward the peripheral region. Because of the hollow density profile, this mode converted magnetosonic wave encounters the lower hybrid resonance again in the peripheral region and can be linearly mode converted to the vacuum electromagnetic mode that reaches the antenna located outside of the plasma. However, such propagation process via the linear mode conversion between bulk-ion modes cannot explain why waves in harmonic cyclotron frequencies of $\omega \simeq (l-1)\Omega_{ci}$ and $\omega \simeq (l-2)\Omega_{ci}$ are also observed simultaneously in the experiment if they are excited in the core region. In this presentation excitation, propagation, and damping of the waves originated from high energy ions will be investigated based on the linear kinetic theory with use of TASK/dp code. With comparing the PIC simulation result, effect of nonlinear scattering processes near the resonances may be examined.

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Dependency of turbulent transport on various local parameters in high temperature tokamak plasmas by using the analysis of electromagnetic micro-instability

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In order to define the operation scenario and predict the turbulent transport level of ITER, it is crucial to evaluate the transport in JT-60SA scenario. In previous analyses, operation scenario analyses [1-3] have shown the feasibility of steady-state operational scenario with higher beta value than the MHD stability limit [2]. According to these works, turbulent transport dominates the heat transport in the steady-state scenario in JT60-SA. In order to estimate the turbulent transport, the micro-instability analysis is the important work. Previous calculation with gyrokinetic simulation in JT-60SA like equilibrium magnetic field has shown that the linear growth rate of the instability can be controlled by changing the magnetic geometry [4]. However, this analysis did not include the effects of kinetic electron and finite beta value. Furthermore, the model magnetic field and local parameters is used.

In this research, we evaluate the dependency of turbulent heat transport on various local parameters, (for example, ion temperature gradient and electron temperature gradient) by using the electromagnetic linear instability gyrokinetic analysis in the JT-60SA high-beta steady-state operation scenario [2] with consistent magnetic geometry and local parameters. Based on the quasilinear heat transport which is calculated by the linear growth rate, we suggest how to estimate variations of several local parameters triggered by the increase/decrease in turbulent heat transports of electron and ion, which is comparable to that in external heating for the steady-state operational scenario. Furthermore, we apply this approach to the JT-60U experiments and verify the effectiveness of it.

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MHD Nonlinear Simulation of ELM current and pressure profile relaxation in a tokamak pedestal

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For realization of nuclear fusion, it is necessary to confine high density and high temperature plasma for a long time. Recent tokamak experiments find out that the H-mode plasma with confinement improved, in accompanied with steep gradients of pressure and mass density in the edge region so called pedestal. In the pedestal, the edge localized mode (ELM) leads to large outward flux of heat and particle, and may cause a damage on the wall of fusion reactor. Thus, the ELM mitigation is an important task in fusion research.

In previous research, onset of the ELM is considered to be related to peeling-ballooning instability. While several simulations have been carried out for quantitative estimation of ELM, the physical mechanism of ELM saturation has not been fully discussed. One of the theories [1] suggest that the peeling-ballooning instability creates a pair of current filaments which are parallel to magnetic field line, but opposite direction to each other. The repulsive force at the filaments acts to eject a plasma blob to the edge region. Our purpose is to reveal the nonlinear dynamic process of the ELM event and relaxation of current and pressure profiles.

We use the nonlinear simulation code MIPS to solve the resistive MHD equations [2]. As the initial condition, we employ the magnetic field configuration similar to that of JT60-U, where a pedestal region for density and pressure is found for $\rho > 0.9$.

In our simulation, we have found growth of the ballooning type mode with high toroidal mode number (n) and result that pressure profile relaxation. Simultaneously, growth of low-n modes is identified. The linear growth rates are also compared with result of the ideal MHD linear stability analysis code MINERVA [3]. More detailed discussions will be given in the conference.

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Experimental study of plasma response to pulsed magnetic field

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In the universe, many nonlinear phenomena are recognized, and they are considered to cause plasma heating and particle acceleration. One of such examples is substorm. Substorm is considered to be caused by plasma compression in geo-magnetosphere with change of the magnetic field topology. The purpose of this study is to clarify the influence of magnetic field topology change on plasma dynamics. An experimental research has been carried out using HYPER-I (High Density Plasma Experiment-I), which is shown Fig.1. A pulsed magnetic field (up to 400 mT) is generated in the opposite direction to the background magnetic field of HYPER-I (50 mT) with solenoid coil. A rising time and a falling time of the pulsed magnetic field are 11 μs and 120 μs respectively. A time evolution of electron density was mesured around the inserted solenoid coil with langmuir probe, which is shown Fig.2. It was observed that the low density region by a factor of 1/10 was formed inside the dipole magnetic field, when the pulsed magnetic field was applied. It was also observed that the high density layer by a factor of 2 was formed at the boundary between the dipole magnetic field region and the background magnetic field region. In presentation, we will discuss about plasma response to the magnetic field topology change.

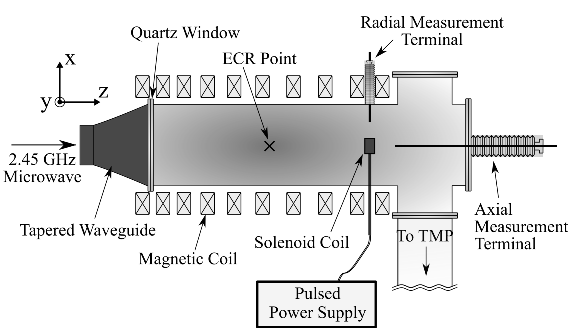

Fig. 1: Experimental system consisting of HYPER-I and pulse magnetic field application unit.

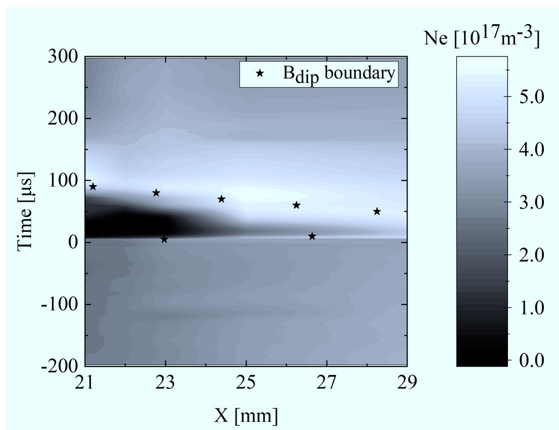

Fig. 2: A contour of time evolution of electron density measured by a Langmuir probe.

Plasma Shape Reconstruction by M-CCS Method in Plasma Merging Experimental Device

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In the toroidal plasmas, the high accurate reconstruction of the plasma shape which is characterized by Last Closed Flux Surface (LCFS) is needed for the reconstruction of the current density profile. It is reported that Cauchy Condition Surface (CCS) method has the higher accuracy and robustness than the Fast Boundary Identification (FBI) method which is generally incorporated in the EFIT code. The probability of the shape identification by CCS method is 100% in the numerical calculation based on the equilibrium solution. On the other hand, FBI method has error rate of 2% and 20% in the high triangularity and the high non-circularity confinement model respectively [1].

In the plasma merging experimental device UTST, the non-negligible eddy current flows in the vacuum vessel in the toroidal direction because of the transient start-up. The capability of Modified Cauchy Condition Surface (M-CCS) method, which reconstructs the plasma shape including the effect of the eddy current, has being investigated experimentally. Fig. 1 shows the experimental result of the plasma shape and eddy current profile reconstruction. The closed red lines in (a) and (b) represent the plasma shapes, and the magenta lines represent the plasma shapes which are measured directly by the magnetic probe array inserted in $-0.23\ \mathrm{m} < Z < 0.23\ \mathrm{m}$. The errors between the reconstruction and the direct measurement are < 42.4 mm and < 33.2 mm in the merging and the after merging phase respectively. The reconstructed eddy current has clear peaks between B-C and around D. The reconstruction is assumed to be qualitatively accurate because these areas correspond to the positions close to the external coils.

In the workshop, the detail of the measurement/analytic environment and the decision of the regularization parameter will be introduced.

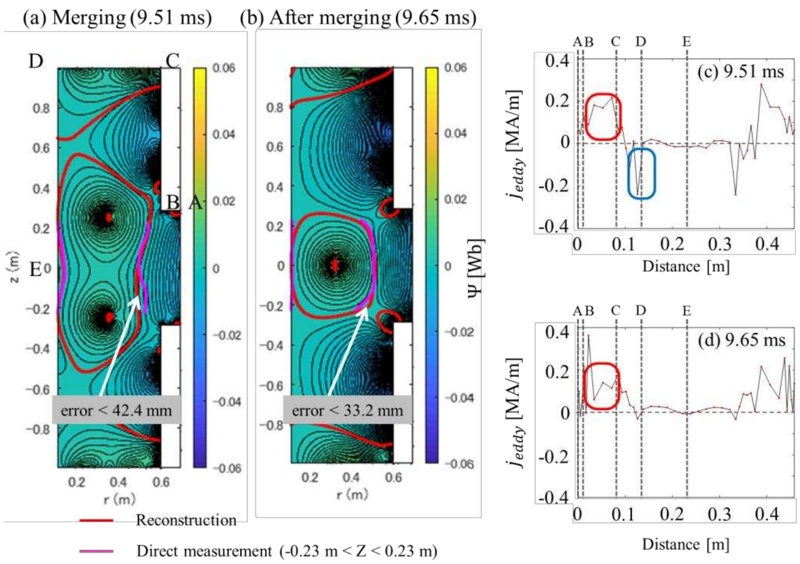

Fig. 1. Reconstructed flux Ψ (a-b) and eddy current j_{eddy} (c-d). The red and magenta lines in (a) and (b) represent the reconstructed and direct measurement plasma shapes respectively. The letters of A-E in (c) and (d) correspond to the corner and inboard-side center position in the axial direction of the vacuum vessel.

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Simultaneous measurement of high frequency magnetic fluctuation and the slowly-changing magnetic field during reconnection

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As a new energy source, nuclear fusion power generation is noticed. In order to realize nuclear fusion power generation, it is necessary to confine plasma at high temperature (about 10 keV) with sufficiently long energy confinement time. The UTST device[1], which produces spherical tokamak (ST) plasma, uses merging start-up method (Axial merging of two STs formed by using external poloidal field coils) as initial heating of ST. During the merging process, magnetic reconnection between poloidal magnetic fields of two STs, which is energy conversion phenomenon from magnetic energy to kinetic/thermal energy of plasma, occur[2].Since the merging of STs involves high toroidal (guide) magnetic field perpendicular to the reconnecting poloidal magnetic field, high-energy electrons, which are accelerated along the magnetic lines by reconnection electric field, are created[1]. These fast electrons may generate localized current channel and change the magnetic configuration. In previous research, magnetic fluctuation of ion-cyclotron frequency range was observed, but the occurrence mechanism and how to affect magnetic reconnection haven't still revealed yet.

In this research, the detailed magnetic field measurement will be carried out to investigate the localized current channel formed inside the reconnection current layer. At this presentation, the relation of the back magnetic field (the global structure of reconnection) and the high frequency magnetic fluctuation will be reported as initial results.

Magnetic field was measured by 2 probe arrays, which are located inside the reconnection current layer. In these 2 probes, pick-up coils were aligned in the radial direction (reconnection outflow direction) to measure axial (reconnected) magnetic field component Bz, One probe consists of high frequency (<5.5 MHz) pick-up coils and the other probe consists of low frequency (<400 kHz) coils. The background and rapidly changing field was measured simultaneously with these 2 probes.

Typical waveforms of magnetic fluctuation (R=350, 370 mm) are shown in Fig. 1. Magnetic fluctuation (~900 kHz) of ion-cyclotron frequency (He^+, ~1.1 MHz) was observed, and propagated to radial direction. The background magnetic field at t=9507 us is shown in Fig. 2. Since the magnetic fluctuation was observed at the vicinity of reconnection X point (Bz = 0), it is suggested that the electron current by parallel accelerated fast electrons would change the local magnetic structure transiently. From now on, each frequency component of magnetic fluctuation will be analyzed and aim to reveal the occurrence mechanism further.

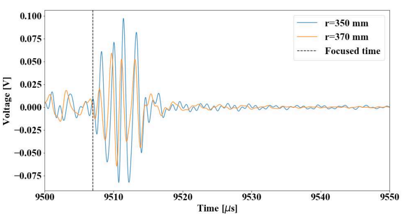

Fig. 1 Magnetic fluctuation

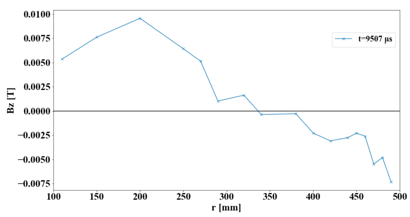

Fig. 2 r-Bz plot at the reconnection time

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Local Potential Measurement during High-Guide-Field Reconnection by using Langmuir Probe in UTST

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Merging formation method of spherical tokamak (ST) plasma is employed in the UTST device to develop an effective ST start-up method without using center-solenoid coil. Two initial STs are inductively generated by swinging the poloidal field coil currents which are placed outside of the vacuum vessel. Then, the initial STs are pushed axially towards the mid-plane of the device and a single ST is formed. At the time of the merging, magnetic reconnection occurs. Magnetic reconnection, which accompanies the energy transfer from the magnetic energy into the plasma thermal and kinetic energy, is utilized for the initial heating of the plasma. During ST merging process, the magnetic field lines have a three-dimensional structure because the toroidal “guide field” which is perpendicular to the poloidal reconnection plane exists. In the UTST, magnetic reconnection with high-guide-field (B_g/B_{rec}~10) brings about the electron acceleration along the guide field. This electron parallel acceleration is considered to cause charge separation which will suppress and finally cancel the parallel component of the reconnection electric field, as observed in a quadrupole potential structure [1]. However, the detailed spatial structure and temporal evolution of the charge separation near the current layer has not been sufficiently understood.

In this research, a Langmuir probe was used for the floating potential measurement. Its electrodes are disposed with interval of d ~ 1.3 mm in the axial direction as shown in the Fig.1. The measurement position (R, Z) = (340 mm, 0 mm) is indicated by black circles in the Fig.2. The contour plot of the magnetic surfaces and the temporal evolutions of the magnitude of the electric field (=V/d) derived from the measured potential difference V between the two probe tips are shown in the Fig.2. Large electric field was observed when the reconnection layer was located near the measurement position (Fig.2 (a)). On the other hand, no clear peak was observed when the measurement position was slightly apart from the reconnection layer (Fig.2 (b)). The observed electric field of < 3 x 10^5 V/m was much larger than the expected value (reconnection electric field x toroidal magnetic field / axial magnetic field ~ 3 x 10^3 V/m) possibly because the probe potential might be influenced by the non-thermal fast electrons. In order to clarify the charge separation phenomenon in the guide field reconnection, further investigation of 2-dimensional potential measurment will be carried out.

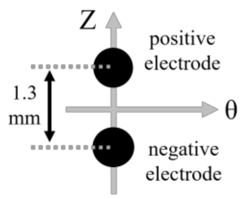

Fig.1 The arrangement of the two tips.

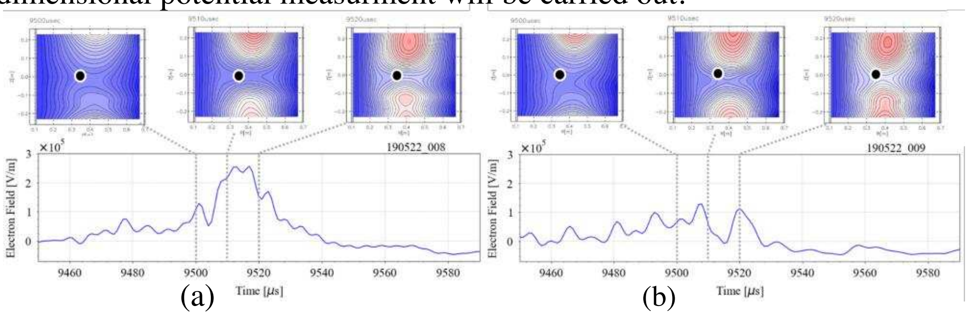

Fig.2 The contour plot of the magnetic surfaces and the temporal evolutions of the electric field.

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Measurement of Soft X-ray emission spatial distribution during high guide field reconnection in UTST

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Introduction

In the UTST, plasma merging method is used to generate spherical tokamaks. Magnetic reconnection occurs under high guiding magnetic fields. the reconnection electric field (Et) and the guide field are parallel near point X, therefore accelerated high-energy electrons are generated. In particle simulation, it is predicted to have a spatial structure along the separatrix [1]. In addition, the emission of soft x-rays along the separatrix structure has been observed in the previous research of UTST. [2]. In order to understand the point where high energy electrons are generated by reconnection and the behavior of high energy electrons after that, it is necessary to measure higher spatial resolution and time resolution.

Measurement method

In this study, we measure the time evolution of the soft X-ray emission distribution along the length of the reconnection current layer using a one-dimensional AXUV photodetector array. A slit with a soft X-ray filter is installed in front of the AXUV. The current signal output from AXUV installed inside the UTST vacuum vessel is converted and amplified to a voltage signal using a preamplifier installed outside the UTST, and measured with a digitizer. The measured line-of-sight position (line-of-sight interval average about 20 mm), is between R = 185 mm - 535 mm. Based on the obtained data, abel inverse transformation is performed on the assumption of plasma axial symmetry to obtain radial distribution of soft X-ray emission. The following measurement results were obtained using two different filters under identical conditions

Measurement result

The measured signals are shown in FIG1. FIG.2 shows Signal ratio Al 0.8 μm to 1.5 μm. In poster session, We will show other result and considerations.

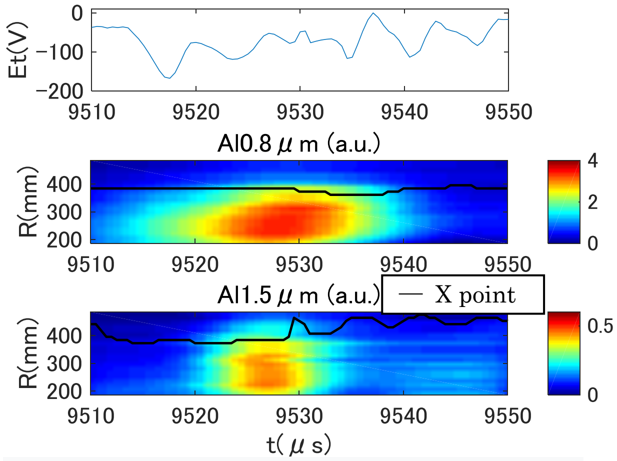

Fig. 1 Time evolution of measurement signal , Reconnection electric field Et and SX signal by using filter Al (0.8 μm),Al (1.5 μm)

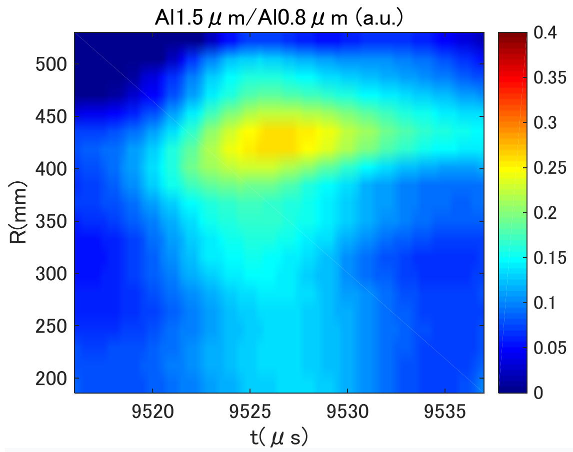

Fig. 2 Time evolution of the ratio of the radial distribution of the line-of-sight integrated signal by Al (0.8 μm) filter to Al (1.5 μm) filter.

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Dynamics of an M3.7 Class Solar Flare on 02 March, 2015

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In this study, we present the observation of an M3.7 class solar flare associated with a violent filament eruption. This eruptive flare was originated from active region NOAA 12290 on 02 March, 2015, which was located close to the western limb of the Sun. For this study, we have used the data from the Atmospheric Imaging Assembly (AIA) on board Solar Dynamics Observatory (SDO) to observe the multi-wavelength evolution of the flare, Reuvan Ramaty High Energy Solar Spectrometric Imager (RHESSI) for the study of thermal and non- thermal emission during the flare, and Global Oscillation Network Group (GONG) for the chromospheric study of the flare. We have discussed the dynamics and the kinematics of the filament eruption and the associated flare using above mentioned data sets. We found that the filament erupted with a speed of ≈ 400 kms^{-1} and associated with a slow (speed ≈ 325 kms^{-1}) Coronal Mass Ejection (CME). During the eruption of the flare, we observed the formation of current sheet in all AIA EUV (94 Å, 131 Å, 171 Å, 193 Å, 211 Å, 304 Å, and 335 Å) wavelengths. The RHESSI X-ray observation evidenced the presence of sources on foot-point and loop-top as reported in earlier observations. Finally we explain our results in light of earlier studied eruption models.

The effects of thermal electrons on whistler-mode waves excited by anisotropic hot electrons: Linear theory and 2-D PIC simulations

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The wave normal angle of excited whistler waves was previously considered to be controlled by the parallel plasma beta ($\beta_{\parallel h}$) of anisotropic hot electrons, while the effects of thermal electrons were usually neglected. By combining both the linear theoretical and 2-D PIC simulation models, we have investigated the effects of thermal electrons on the whistler anisotropy instability. In the high-beta ($\beta_{\parallel h} \geq 0.25$) regime, the wave normal angle of the dominant whistler mode with the largest growth rate is always zero degree, which is not affected by thermal electrons. While, its wave frequency and linear growth rate decrease with the density and temperature of thermal electrons. These results are also confirmed by PIC simulations. In the low-beta ($\beta_{\parallel h} \leq 0.25$) regime, with the increase of the density and temperature of thermal electrons, the wave normal angle of the dominant whistler mode turns to zero from a large value. This change could be due to the stronger damping caused by thermal electrons for oblique whistler mode, since oblique wave usually has a smaller cyclotron resonant velocity than parallel wave. PIC simulations also show a consistent result, but reproduce a broad magnetic spectrum, even in the case including sufficient thermal electrons. Furthermore, thermal electrons with large parallel velocities are resonantly accelerated in the perpendicular direction, while part of hot electrons are trapped and accelerated in the parallel direction. Our study suggests that the wave normal angle of whistler mode in the Earth's magnetosphere could be determined by both anisotropic and thermal electrons.

Spatial structure of coherent whistler mode wave packets in Earth's bow shock: MMS observation

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The Fermi acceleration at a shock wave is one of the leading mechanisms for the nonthermal particle acceleration. In this mechanism, it is necessary to confine charged particles in the vicinity of the shock wave while charged particles are being accelerated, which requires pitch angle scattering due to wave-particle interactions. In the case of electrons, whistler mode waves are considered to play a major role in the pitch angle scattering. There have been reports of coherent whistler mode waves propagating parallel to the magnetic field in the vicinity of the shock wave [1]. Recently, it was found that such whistler mode waves are indeed resonantly interacting with suprathermal electrons [2]. However, the relation between whistler mode waves and electron scattering (or acceleration) efficiency has not yet been clarified.
In order to resolve the issue, we performed an analysis for high-frequency (~100 Hz) coherent electromagnetic waves observed during bow shock crossings with enhanced energetic electron flux observed by NASA's MMS (Magnetospheric MultiScale) spacecraft. In particular, we report results for the following two bow shock crossing events: 11:44 UT on October 7, 2015 (Event 1), and 10:29 UT on December 6, 2016 (Event 2). The spacecraft separation was 20 km and 7 km for the Event 1 and Event 2, and comparison between the two may enable us to estimate the scale size of whistler mode wave packets. We applied a band pass filter with for the frequency range 100-250 Hz (fce > 1 kHz) for Event 1, and 50-150 Hz (fce ~ 300 Hz) for Event 2 where prominent peaks were observed in the magnetic field power spectra. We confirmed that whistler mode waves appeared sporadically as wave packets with a short duration (50 - 100 ms). We used MVA (Minimum Variance Analysis) for determining the wave propagation direction. Note that we eliminated the 180-degree ambiguity by referring the Poynting vector direction. Also, we estimated the wavelength from the wave electric-to-magnetic field amplitude ratio using Faraday's law. The obtained wavelengths of the whistler mode waves were roughly 10 km. This indicates that the spacecraft separations were larger (smaller) than the wavelength for the Event 1 (2). By doing the same analysis for each spacecraft, we found that wave packets observed during Event 1 were almost always uncorrelated. On the other hand, both correlated and uncorrelated wave packets were found for Event 2. This suggests that the whistler mode wave packets have spatial scale of a few km. We estimated instantaneous wave properties such as amplitude, frequency, and phase by using a non-linear fitting method [3].By comparing the fitting results between different spacecraft, we will estimate the spatial scale sizes of wave packets in parallel and perpendicular directions with respect to the magnetic field.

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Relativistic electron acceleration by whistler-mode chorus waves in 1D, 2D, and 3D magnetic field models

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We evaluate the acceleration efficiencies of relativistic electrons under a 1D, 2D, and 3D model magnetic fields. We perform test-particle simulations and analyse nonlinear trapping motions of resonant electrons in each model. As a chorus wave model, we assume that a chorus wave packet generated at the magnetic equator propagates along the magnetic field to higher latitudes. When we perform simulations with the whistler mode wave, the cyclotron resonance with energetic electrons occurs at the similar timing in each model. Although we find relativistic turning acceleration (RTA) [1] to take place in each model, acceleration efficiencies of resonant electrons are different in these models. In terms of the numerical Green's function [2], we find a clear difference in time evolution of the distribution function in energy and equatorial pitch angle. The energy gap between resonant electrons and non-resonant electrons in the 1D model is slightly different from those in the 2D and 3D models. The energy gap in the 3D model is the largest among the three magnetic field models. This difference is due to additional oscillations in the velocity phase space, which only occur in the 2D and 3D models. These oscillations occur because the magnitude of the magnetic field changes during one period of relativistic cyclotron motion, affecting the nonlinear trapping conditions of resonant electrons.

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Relativistic acceleration of energetic protons by electromagnetic ion cyclotron waves in the Jovian magnetosphere

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We perform test particle simulations of nonlinear interaction between energetic protons and EMIC waves. We assume a coherent EMIC waves that have a constant frequency and propagate parallel to the magnetic field. We find that protons can be trapped and accelerated by EMIC waves. We find a very efficient acceleration process of protons in which kinetic energy of protons increases while directions of parallel velocities reverses when we assume parameters in the Jovian magnetosphere. We notice that this phenomenon is very similar to the interaction process between relativistic electrons and whistler-mode waves, which is called Relativistic Turning Acceleration (RTA) [1]. In order to analyze the phenomena, we have developed nonlinear trapping theory of interaction between relativistic protons and EMIC waves. Next, we compare the theory and simulation results. We confirm that the results satisfy the conditions for RTA. Following the trajectories of many resonant protons, we obtain time evolution of the distribution function of relativistic protons as a function of energy and equatorial pitch angle based on the numerical Green˙s function method [2].

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[2] Y. Omura, Y. Miyashita, M. Yoshikawa, D. Summers, M. Hikishima, Y. Ebihara, and Y. Kubota (2015), Formation process of relativistic electron flux through interaction with chorus emissions in the Earth˙s inner magnetosphere, J. Geophys. Res. Space Physics, 120, 9545´9562, doi:10.1002/2015JA021563, 2015.

Solitary Wave in a Pair Ion Plasma

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Using Reductive Perturbation Technique (RPT), Zakharov-Kuznetzov (ZK) equation is derived for ion acoustic solitary waves in a pair ion magnetized plasma consisting of hydrogen ions, both solar and cometary origin of electrons and positively and negatively charged pair ions. Kappa distribution function is used to describe both kind of electrons. The Chew, Golberger-Low (CGL) theory has been included in the derivation to study the anisotropic effects of different ions in the plasma [1]. The present study is mainly focuses on the modeling of a plasma near comet Halley [2,3]. The relevant observational physical variables were taken and plotted for width and amplitude of solitary waves. From the plots, it is seen that different anisotropy affects amplitude and width of the solitary waves differently. The theoretical equations derived are applicable to any plasma environment where similar plasma species are present.

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Observational Evidence for Stochastic Shock Drift Acceleration at Quasi-perpendicular Earth's Bow Shock

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High-energy charged particles are ubiquitous in space. The first-order Fermi acceleration at collisionless shocks is one of the leading mechanisms that may produce such high-energy non-thermal particles. Indeed, radio, X-ray, and gamma-ray observations strongly suggest that shock waves associated with supernova remnants, pulsar winds, relativistic jets in active galactic nuclei and gamma-ray burst are accelerating relativistic electrons. On the other hand, in-situ observations in the heliosphere have shown that the acceleration of electrons is, in general, weak or even absent in many of the shock crossings.

We have recently proposed a theory for electron acceleration at shocks that may resolve the observational controversy. The theory referred to as stochastic shock drift acceleration (SSDA) extends the classical shock drift acceleration (SDA) model by introducing stochastic pitch-angle scattering during electrons are interacting with a collisionless shock. The model predicts a number of features seen in observations that could not be explained by the classical SDA. We here present detailed comparison between the theory and observations by using NASA's Magnetospheric MultiScale (MMS) spacecraft. We analyzed an Earth's bow shock crossing event on December 9, 2016. In the shock transition layer, we found (1) exponential increase of energetic electron fluxes toward downstream, (2) nearly isotropic pitch-angle distribution of electrons, (3) enhanced high-frequency electromagnetic fluctuations consistent with whistler mode waves, all of which are consistent with theoretical predictions. We will present more quantitative comparisons between the theory and observation for the properties of non-thermal electron spectra. The result suggests that the SSDA theory is fully consistent with the observations. We will also discuss astrophysical implication of the present result.

Flux decrease of outer radiation belt electrons associated with solar wind pressure pulse: A Code coupling simulation of GEMSIS-RB and GEMSIS-GM

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Relativistic electron flux of the outer radiation belt dynamically changes in response to solar wind variations. The variable wind conditions cause the flux drop-out of the outer belt electrons. Magnetopause shadowing (MPS) is proposed to cause a rapid loss process of outer belt electrons (e.g.,Kim et al.,2008). It has been expected that the cross-field transportation due to convection and the dayside compression of the magnetosphere causes loss of trapped electrons in MPS. In this study, we investigate how radiation belt electrons are actually lost into the interplanetary space. We use the code-coupling simulation of a test-particle simulation code (GEMSIS-RB: Saito et al., 2010) and a global MHD magnetosphere simulation code (GEMSIS-GM: Matsumoto et al., 2010) by focusing the equatorial pitch angle and local time dependence. We calculate trajectories of guiding-center of electrons in electromagnetic fields calculated from GEMSIS-GM. Electrons are distributed from L = 6 to 11 with initial energies from 1 MeV to 10 MeV. Initial pitch angles of electrons are distributed from 50 degrees and 90 degrees. In this simulation, the solar wind dynamic pressure and the magnetopause stand-off distance change as follows; [i] The stand-off distance of the magnetopause at the subsolar point is 12 R_E with the initial dynamic pressure of 1.0 nPa. [ii] The solar wind dynamic pressure increases to 2.5 nPa, and the magnetopause moves to 9 R_E. [iii] The dynamic pressure decreases, and the inflation of the magnetopause takes place. The stand-off distance of the magnetopause moves back to 10 R_E. During phase [ii], the high-latitude magnetic reconnections occur at dawn-side. Several electrons escape from the field lines that connect to the interplanetary magnetic field along the field line in the dawn side. Simultaneously, the high-latitude reconnections occur at the high-latitude in the dusk side. In phase [iii], the trapped electrons in the magnetosphere escape from the field lines that connect to the interplanetary magnetic field in both the dawn and dusk sides. The loss of electrons in phase [ii] is enhanced due to outward motion of the trapped electrons caused by the dawn-to-dusk electric fields during the inflation of the magnetosphere. The study proposes a new model that enables radiation belt electrons to escape to the interplanetary space through the dayside magnetic reconnection.

Critical Parameters of Photospheric Magnetic Field to Produce Eruptive Flares in Solar Active Regions

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Solar flares and coronal mass ejections (CMEs) are eruptive phenomena caused by magnetic field in the solar corona. In particular, large eruptive events originate in active regions (AR) on the solar surface. However, it is still unclear what determines the capability of an AR to produce eruptive flares and CMEs, and it hinders our ability to predict CMEs. In this study, we propose a new parameter $\mathrm{r_m}$ to measure the possibility that a flare on an AR can be eruptive and produce a CME. The parameter $\mathrm{r_m}$ is defined by the ratio of the magnetic flux of twist higher than a threshold $\mathrm{T_c}$ to the surrounding magnetic flux. The value of $\mathrm{r_m}$ for each AR can be estimated using the nonlinear force-free field (NLFFF) extrapolation. Based on the data obtained by the Solar Dynamics Observatory (SDO)/Helioseismic and Magnetic Imager (HMI), we calculated the values of $\mathrm{r_m}$ for 29 ARs at 51 times before to flares larger than M5.0 class. We find that the foot-point of field lines with twist larger than 0.2 can well represent the flare ribbons, and field lines that overlying and fencing in these region will confine the eruption, generating confined flares. The discriminant analysis shows that $\mathrm{r_m}$ is moderately able to discriminate ARs which have capability to produce eruptive flares.

Auroral Growth and Transition to Alfvenic Turbulence in the Magnetosphere-Ionosphere Coupling

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Spontaneous generation of auroral arc structures and their nonlinear dynamics are investigated by means of the linear analysis and numerical simulations of the feedback instability in the magnetosphere-ionosphere (M-I) coupling. The shear (or kinetic) Alfven waves are amplified through the feedback instability when the background convection electric field (or the ionospheric current driven by the electric field) exceeds a critical value. In a saturation phase of the instability growth, the Kelvin-Helmholtz type mode is secondary destabilized through the enhanced flow shear accompanying with auroral arcs. After the saturation, one finds a nonlinear stage with fully developed Alfvenic turbulence of which energy spectrum has a typical power-law scaling of $k_\perp^{-5/3}$. It also demonstrates a correlation of the parallel and perpendicular wavenumbers consistent with an ansatz of the critical balance in the Alfvenic turbulence caused by interaction of counter-propagating Alfven waves.

Solar Storm Effects on South Atlantic Anomaly: Test Particle Simulations

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We developed a three-dimensional relativistic test particle code to calculate the high-energetic proton trajectories, in a background magnetic field calculated by the Tsyganenko model TS05. The objective of this research was to study the solar storm index (Dst index) effects on the three-dimensional proton flux distribution inside the South Atlantic Anomaly. It is well-known that the South Atlantic Anomaly (SAA) is considered as a source of additional radiation dose on Low Earth Orbit (LEO) satellites, which can affect and damage in some cases, the internal electron components of the spacecrafts. It was found that, in a very short time scale (within minutes), the proton flux penetration was increased by 150 km, when Dst index decreased from -7 nT to -210 nT, for protons of energy range 150 to 400 MeV. After few more minutes, the proton flux decreased at all altitudes. This result demonstrated the proton injection and escape in the inner radiation belt during intense solar storm conditions.

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Dependence of the Dipole Component Dominancy on the Rayleigh Number and Inner Core Size in Geodynamo Simulations

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Geomagnetic field is generated by a dynamo action in the fluid outer core. Studies of the thermochemical evolutions of the Earth's core suggest that the solid inner core has been growing up to the present size for approximately one billion years [1]. Results of numerical dynamo simulations with various radius ratios (r_i/r_o; ratio of inner to outer core radii) indicates that the sustained magnetic field is categorized into dipolar-dominated or non-dipolar-dominated regime [2,3]. However, any dominant factors controlling the regime have not been fully understood. In the present study, we perform dynamo simulations with various inner core radii using a geodynamo open code Calypso to investigate the characteristics of the generated magnetic field. We change the Rayleigh number (Ra)and the radius ratio to be r_i/r_o = 0.15, 0.25, and 0.35. Then we examine the dominancy of the dipole component in two approaches; one is the dopolarity, f_{dip}, which is the ratio of the amplitude of the axial dipolar magnetic field to the total amplitude, and the other is the comparison of the magnetic energy of l=1 in simulation data to the extrapolated value for l = 1 in the fitting curve derived from odd degree components from l = 3 to l = 19.

In r_i/r_o = 0.25 and 0.35 cases, f_{dip} is approximately 0.8 at $Ra/Ra_{crit} \fallingdotseq 2.0$ and gradually decreases to approximately 0.45 with increase of Ra/Ra_{crit} up to around 6.0, where Ra_{crit} is the critical Rayleigh number. By referring to the obtained fitting curve, we find that the dipolar magnetic energy is more than 2 and 4 times larger than the extrapolated value for l = 1 at $Ra/Ra_{crit} \fallingdotseq 2.0$ and decreases with increase of Rayleigh number in r_i/r_o = 0.25 and 0.35. The dependency of the dipole component dominancy on the Rayleigh number is similar in both radius ratio cases. However, in r_i/r_o = 0.15 cases, f_{dip} is approximately 0.4 at $Ra/Ra_{crit} \fallingdotseq 8.0$ and decreases to approximately 0.1 with increase of Ra/Ra_{crit} up to around 15.6. At $Ra/Ra_{crit} \fallingdotseq$ 8.0, the amplitude of the dipole component is comparable to the extrapolated value from the fitting curve. At Ra/Ra_{crit} > 10.1, the magnetic energy for l = 1 component is smaller than that for l = 2 component. Consequently, the magnetic field obtained in the simulation results is non-dipolar. To summarize above, we categorize the present simulations as shown in Figure 1. The axial dipole component becomes smaller in all three ratio cases for larger Rayleigh number. Non-dipolar component becomes large for the smaller inner core. In order to discuss whether this trend is general or not, we carry out further simulations with smaller Ekman number than the present value.

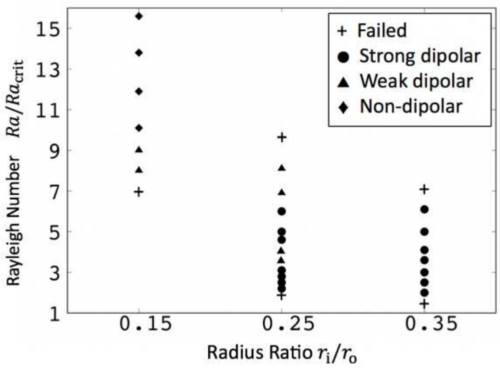

Figure 1 Dynamo regime in various radius ratios

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Electron beam instability in the imhomogeneous field on the collisionless magnetic reconnection with a strong guide field

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Magnetic reconnection is a fundamental physics mechanism in magnetized plasma that causes a topological change of magnetic field lines and a conversion of magnetic energy to kinetic energy leading to a self-organization of plasmas in laboratory and space. It is considered that the two-fluid effects or the kinetic effects play an important role to enhance the reconnection rate in colllisionless plasmas. Anomalous resistivity (AR) is one of the candidates that contributes to continuous drive of the magnetic reconnection.

In our previous study, we have carried out numerical simulations of the collisionless magnetic reconnection by means of the gyrokinetic model of a slab plasma with a strong guide field [1][2]. During the reconnection, electrons are accelerated along the guide field by the parallel electric filed. In this model, the total distribution function F is described as $\mathrm{F} = F_M + f = (1 + Uv_\parallel)F_M \sim 1/\sqrt{2\pi}\ \exp(-(v_\parallel - \mathrm{U})^2/2)$ under the approximation of $U \ll v_{ts}$, where F_M is Maxwellian, f is the perturbed distribution function and U is a beam velocity component. The liner analysis by use of the dispersion relation of plane waves shows that the kinetic Alfvén waves (KAW) are destabilized when the electron beam velocity exceeds the Alfvén speed.

Our present goal is the stability analysis in an inhomogeneous field that is found during the collisionless magnetic reconnection, where we need to deal with the total distribution function during the reconnection. In this study, we have carried out numerical simulation of the magnetic reconnection process triggered by the electron inertia by use of a full-f gyrokinetic model with the translational symmetry in the direction of the guide field where the shifted Maxwellian is formed at the X-point by the parallel electric field. The parallel electron beam formed on the reconnection plane (xy-plane) is shown in Fig.1. We have also developed a simulation model for the linear stability analysis of the KAW in the configuration obtained during the reconnection. In this model, we use result of the two dimensional simulation as the equilibrium $(\mathrm{k_z} = 0)$ and solve the time-evolution of the perturbation part $(\mathrm{k_z} \neq 0)$. We will discuss the result of the stability analysis at the conference.

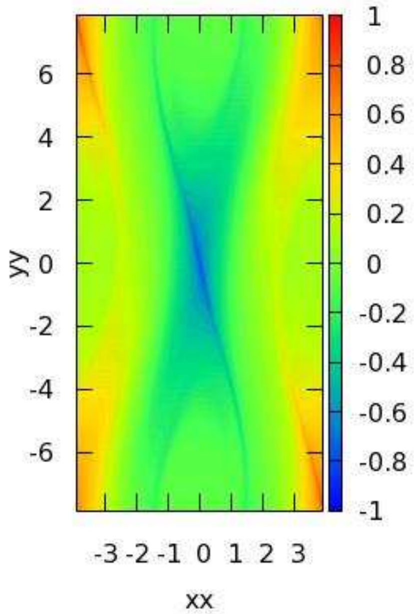

FIG.1 the parallel electron beam on the reconnection plane in the nonlinear phase during the reconnection

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Auroral Cavity Mode with Ionospheric Inhomogeneity

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The feedback instability in the ionospheric Alfv¶n resonator in Earth˘s magnetosphere has been investigated by many researchers. This instability leads a cavity mode which is known as a phenomenon originating from the fact that Alfv¶n speed has a great gap between topside of the ionosphere and bottom side of the magnetosphere; the ratio is about 10 or 100. Most of previous studies have neglected thickness of ionosphere and treated the ionosphere as a height-integrated conductive layer, because it is much thinner than Alfv¶n wavelength. However, a recent work implies that taking thickness and height dependent of ionosphere into consideration leads stabilizing effects on the ionospheric feedback instability by linear simulations [1].
In this work, our goal is specifying marginal ion-neutral collision frequency which is able to trigger the feedback instability for each cavity modes by linear eigenmode analysis with ionospheric inhomogeneity. So, we extended a previous work of cavity mode with height-integrated conductive layer model [2] to inhomogeneous ionosphere model. Then, we referred model description of past engenmode analysis of field line resonator [3]. And we find that high frequency harmonics decays sooner than low one as ion-neutral frequency goes up.

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Application of Contour Dynamics Method to the Vlasov-Poisson Plasma with the Periodic Boundary

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Zabusky, Hughes, and Roberts proposed a contour dynamics algorithm for the Euler equations of fluid dynamics in two dimensions [1]. In the paper, they succeed in calculating time development of contours of vorticity on the x-y plane with the contour dynamics(CD) algorithm, where the Euler equation is solved by using contours of vorticity, piece-wise constant function, and line integrals of Green's function on the contours. The CD method does not use underlying lattice, but employs nodes on the contours, and it can lead to more accurate calculation for complex deformation of vorticity.

This method is also applied to the Vlasov-Poisson system. In order to study the CD in the Vlasov-Poisson plasma, we have developed a method to implement the periodic boundary condition of the electrostatic potential and its derivative. To check validity of out method, we test the linear Landau damping by means of the CD scheme.

While discretization of the distribution function might lead to some differences from that with continuous distribution, soundness of our new scheme is confirmed in comparison with analytical solutions.

We have also investigated in the nonlinear Landau damping. Because the CD scheme enable us to chase the deformation of contours accurately, we can draw an accurate picture of map from the initial to the nonlinear steady. Now, we try to measure the deformation of the contours, to deepen our knowledge on the dynamics, such that, which contours and points are deformed at most, how they are affected by the electric field, and what their roles are in the dynamics.

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Modeling of solar active regions using local linear force-free fields to estimate magnetic twist

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The prediction of solar flares is an important issue for space weather forecasting. Although solar flares are believed to be caused by the magnetohydrodynamic (MHD) instability in solar active regions, the method for accurately evaluating the stability of solar magnetic field is not yet established. Recently, Ishiguro & Kusano (2017) proposed that a new instability called the Double Arc Instability (DAI) plays a role of initial driver of solar flares and the critical parameter κ for this instability can be used to evaluate the stability of active regions[1]. The parameter κ can be derived by the integration of the magnetic twist T_w as the function of magnetic flux. One way for it is given by the nonlinear force-free field (NLFFF) extrapolation using the photospheric vector magnetic field data[2]. However, the NLFFF extrapolation demands heavy computation and it sometimes cannot well work as a model of solar coronal magnetic field because the force-free condition is limited on the photosphere. Therefore, in order to improve the efficiency and applicability of the flare prediction using κ, it may be required to develop a method to approximately but much quickly capture the overall features of magnetic field in solar active regions, especially in the flare triggering region. From this point of view, we try to develop a method to extract the characteristic feature of magnetic field in solar active regions using the linear force-free field (LFFF) model. For this objective, we compare the several methods to accurately capture the structure of T_w using LFFF. In this study, we report the result of the analysis for the solar active region NOAA 11429.

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Dependence of whistler wave amplitudes on scattering process of relativistic electrons in the Earth radiation belts

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Whistler mode chorus waves cause scattering and acceleration of energetic electrons in the Earth inner magnetosphere. The interaction processes have been modeled as diffusive process in the quasi-linear approximation. The pitch angle diffusion coefficients of the pitch angle scattering depend on the power of chorus waves, so that it is expected that the scattering rate also depends on the wave amplitude. On the other hand, several previous studies indicated that the Lorentz force by the wave magnetic field is larger than the mirror force if the wave amplitudes increase and the electron trajectories in the velocity space are different from the diffusive process. In this study, we investigate chorus wave amplitude dependence of electron scattering using the GEMSIS-RBW simulation code [Saito et al., 2012]. The GEMSIS-RBW simulation demonstrates generation of periodical rising-tone chorus waves propagating along a magnetic field line to higher latitudes, and calculates variations of local pitch angle and energy by the imposed waves along the field line. At small wave amplitudes, time variations of pitch angle and energy of electrons are similar to diffusive process, and random scattering processes are seen in the velocity space. At large wave amplitudes, some electrons increase both pitch angle and energy at interaction with the first rising tone, and then they decrease these parameters at interaction with the second rising tone. The process in the first rising tone seems to be the phase trapping, while the process in the second rising tone seems to be dislocation as suggested by Bortnik et al.[2008]. Therefore, nonlinear scattering processes, which are phase trapping and dislocations, occur during the interactions with periodical rising-tone chorus waves with large amplitudes, which are quite different from diffusive process. We calculate parameter ρ of each test particle that is a proxy of ratio of Lorentz force of electromagnetic waves and mirror force [Saito et al., 2016] and we discriminate different properties of electrons, i.e., diffusion, phase-trapping and dislocation as function of ρ .

Turbulence in clusters of galaxies

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Magnetic fields in clusters of galaxies play a critical role in shaping up the intracluster medium. Their existence has been established through the rotation measure of polarized radio galaxies and the synchrotron emission of cluster-wide diffuse sources. In the so-called Sausage relic, which is one of giant radio relics detected in a cluster outskirt, for instance, the magnetic fields are believed to have a few μG strength and a Mpc scale. The observed magnetic fields are conjectured to be produced by the process of small-scale turbulence dynamo due to turbulence in the intracluster medium (ICM). To investigate the dynamo origin, we simulate the development of turbulence and the follow-up amplification of magnetic fields in galaxy clusters using a three-dimensional MHD code. Turbulence is induced in highly stratified backgrounds expected in clusters and driven sporadically mimicking major mergers. We here present the results, aiming to answer whether the turbulence dynamo scenario can explain the observed magnetic fields in clusters of galaxies.

Firehose instability in Astrophysical and Space Environments

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The firehose instability is driven by a pressure anisotropy in a magnetized plasma when the plasma has $T_{\parallel} > T_{\perp}$, that is, the temperature along the magnetic field is higher than the perpendicular temperature. Such condition occurs commonly in astrophysical and space environments, for instance, when there are beams aligned with the background magnetic field. Recently, it was argued that around weak quasi-perpendicular shocks in high-β plasmas of the intracluster medium, shock-reflected electrons propagating upstream cause the temperature anisotropy of $T_{\parallel} > T_{\perp}$. This electron temperature anisotropy can trigger the electron firehose instability (EFI). In the study, the kinetic properties of the EFI are first examined by the linear stability analysis based on the kinetic Vlasov-Maxwell theory and then further investigated by 2D Particle-in-Cell (PIC) simulations, especially focusing on those in high-β (β~100) plasmas. We then discuss the implication of our work on electron acceleration in ICM shocks in clusters of galaxies.

The MHD simulation towards a solution of filament formation and the initial condition of star formation in molecular clouds

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Stars are formed in high density regions in molecular clouds. Recent observations have shown that star forming high density regions are filamentary in general [1]. Furthermore, it has been clarified that star formation occurs in filaments whose line-mass is larger than the critical value above which gas pressure is unable to support self-gravity. Therefore, it is necessary to make clear when and how the filament becomes super critical and causes star formation. There are previous theoretical studies on the filament formation. By using numerical simulations, it is discovered that a filament is formed by a simple shock compression of molecular clump if effect of magnetic field is taken into account [2]. In fact, molecular clouds are often compressed by shock waves due to supernovae more than about 30 times in their lifetime. This means that the collision between shock waves and molecular clouds is quite universal. It has also been shown by numerical simulations that the formed filaments evolve into star forming filaments [3]. In this study, we perform three-dimensional, isothermal, ideal MHD simulations of molecular gas collisions to simulate molecular cloud-shock wave interactions. Then, by changing initial conditions, such as shock strength, duration and cloud density, we clarify the detailed condition of filament formation. Our theoretical model predicts that there exists a threshold shock strength above which dense filaments are formed in the shock compressed layer, and there exists a critical shock duration beyond which star formation can be triggered in the filaments.

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Formation of Massive Star Clusters by Fast HI Gas Collision

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The most important star formation factor at the galactic scale is the formation of star clusters called Young Massive Clusters (YMC). In typical YMC, so many stars ($M > 10^4 \mathrm{M}_\odot$) are packed in only a few pc scale. YMCs play a crucial role in galaxy evolution due to their UV radiation, stellar winds, and supernovae. However, the formation mechanism of YMCs has not yet been well understood. This is because it is difficult to form YMC precursor cloud which is massive and compact enough to evolve into a YMC. On the other hand, recent observational study suggests that YMCs can be formed as a consequence of fast HI gas collision ([1],[2]). In this research, we study theoretical aspect of the above YMC formation scenario using 3DMHD simulation with effects of self-gravity and radiative cooling. By analyzing result of the simulation, we can understand how gravitaitonally bound gas clump is formed in the shock compressed layer created by the HI gas collision. As a result of the simulation, we found that massive and compact gas clumps with $M \sim 10^4 \mathrm{M}_\odot, L \sim 4\mathrm{pc}$ can be formed in the shock compressed region. Such a massive and gravitationally bound clump can be regarded as YMC precursor clouds.

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Tracking the linear stage of instability in finite beam plasma System

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In astrophysical systems and laboratory experiments, the electron beam has a finite extent. In earlier studies the role of the finite extent of the beam was never explored. It was inherently assumed that the boundary effects due to the finite system would merely have a small incremental impact. This assumption took a blow when studies in our group showed that the finite extent led to a possibility of entirely new mode to generate magnetic fields at the scale length of the beam size. This mode is responsible in generating long scale magnetic field. It has distinct characteristics features [1] compared to the well known Weibel and Kelvin Helmholtz modes perative in the beam plasma propagation system. For instance, it is the fastest mode which appears in the electron beam plasma system and only at later time does Weibel and Kelvin-Helmholtz modes appear. It generates magnetic fields at the longer scale length of the transverse beam size whereas Weibel kicks at electron skin depth scales. We propose here a unique way of capturing this mode in the linear phase experimentally. And the experiments confirm our proposal. The technique will be discussed in detail and it essentially relies on using the probe beam from the back of the target.

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Oscillations of Accretion Disks around a Supermassive Black Hole

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Quasi-periodic oscillations (QPOs) are observed in galactic black hole candidates, neutron stars, and blazars. Recently, three-dimensional radiation magnetohydrodynamic simulations indicated that quasi-periodic oscillations are excited in accretion disks around a supermassive black hole [1]. The time scale of oscillation is 10^6 sec for a 10^7 solar mass black hole. It corresponds to the Keplerian rotation period around the interface between the hot radiatively inefficient accretion flow (RIAF) near the black hole and the radiation pressure dominant disk outside 20 Schwarzschild radius. The oscillations appear when the accretion rate is around 10% of the Eddington accretion rate. We explore the possibility that these oscillations are excited by the viscous pulsational instability in accretion disks. We extend the axisymmetric simulations of the radial disk oscillations around the last stable orbit of the black hole accretion flows [2] to this intermediate region between RIAF and optically thick disk. Oscillations can be excited when the alpha-viscosity is large enough [3]. We compare our results with the results of 3D radiation magnetohydrodynamic simulations and discuss the physical mechanism of the oscillation.

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PIC simulation on nonlinear development of lower-hybrid instabilities driven by energetic ions

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Instabilities driven by energetic ions are important issues both for space plasmas and magnetic fusion plasmas. Radio Frequency (RF) waves in the range from the ion cyclotron frequency to the lower hybrid resonance frequency are often observed during the period of neutral beam injection (NBI) in Large Helical Device (LHD) plasmas[1]. The experimental results showed that the peak frequency in the Lower Hybrid Wave (LHW) region has a positive correlation with the electron density and the ion cyclotron emissions (ICEs) have much larger amplitudes than LHW. These waves can be excited by instabilities due to energetic ions generated by the NBI perpendicular to the magnetic field. The simulation study[2] confirmed that energetic ions have a non-Maxwellian ring-like distribution in the velocity space perpendicular to the magnetic field by setting them only in the initial phase.

Using a one-dimensional, electromagnetic, Particle-In-Cell (PIC) code, we study instabilities driven by energetic ions assuming that the energetic ions have a non-Maxwellian ring-like or torus-like distribution in the velocity space perpendicular to the magnetic field. This PIC code enables us to self-consistently simulate full dynamics of electrons and ions and evolution of electromagnetic fields, using the full Maxwell's equations and the equations of motion of particles. We focus on the nonlinear evolution of LHW and ICEs caused by continuous energetic-ion injection into a plasma.

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Effect of Turbulence and sonic Mach number on Daivs-Chandrasekhar-Fermi method

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Davis-Chandrasekhar-Fermi (DCF) method is a tool that is widely used to obtain the strength of the mean magnetic field projected on the plane of the sky. However, it may overestimate the strength of the magnetic field when there are many independent structures (or, eddies) along the line of sight. Recently, Cho & Yoo (2016) proposed a modified DCF method that corrects such an effect.
In this talk, we compare the conventional DCF method and the modified DCF method for various sonic Mach numbers and driving schemes. We find that, when we apply the conventional DCF method to turbulence generated by solenoidal and compressive driving schemes, the results are notably different. In particular, when there are many independent eddies along the line of sight, the estimates of the plane-of-sky mean magnetic field for compressive driving show strong dependence on the sonic Mach number, while those for solenoidal driving exhibit a very weak dependence on it. We find that intermittency of magnetic and density structures is responsible for the sonic Mach number dependence of the conventional DCF method. On the other hand, the modified DCF does not show strong dependence on the sonic Mach number or the driving scheme.

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3D-MHD Simulation of Prominences Formation in the Galactic Center

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We present the results of three-dimensional magnetohydrodynamic simulations of the formation of molecular loops found by CO line survey of the galactic central region by NANTEN telescope [1]. Since it is hard to lift the dense molecular gas, Peng & Matsumoto (2017) applied the reconnection-condensation model of solar prominences (Kaneto & Yokoyama 2015, 2017) to galactic gas disks [2][3][4]. They showed by two-dimensional magnetohydrodynamic simulations that cold, dense filaments can be formed around the bottom of magnetic flux ropes produced by motions at the footpoints of magnetic arcades anchored to the galactic gas disk. We found by 3D-MHD simulations that dense molecular gas in the filament slides down along the longitudinal magnetic fields, and forms a molecular loop. We discuss the possibility that supersonic downflow of molecular gas forms shock waves which correspond to the location of large velocity dispersion.

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THE FORMATION OF OVER-IONIZED PLASMA BY SUPERNOVA EXPLOSION

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When a stellar makes a supernova explosion, its outer layer jumps out at supersonic velocity, and a shock wave is generated in the surrounding interstellar medium (ISM). The shock wave sweeps and collects the ISM, and by heating, an high temperature object called Supernova Remnant (SNR) is formed. The energy that the shock wave gives to the interstellar space is large, and the interaction between the shock wave and ISM is very important. Recent observations of gamma rays have provided observational suggestions that shock waves and molecular clouds are colliding [1]. However, theoretical studies on shock wave propagation in a realistic ISM where temperature and density change by several orders of magnitude are extremely insufficient. In this study, we focused on the over-ionized plasma discovered by X-ray observation of the high temperature plasma behind the shock wave in order to investigate the collision phenomenon of the shock wave and the molecular cloud in detail [2]. Over-ionized plasma is an ionized non-equilibrium plasma in which the degree of ionization is higher than the equilibrium state. As one of the formation factors, thermal conduction cooling by collision of high temperature plasma and molecular cloud has been proposed [3]. However, it has not been well investigated that a over-ionized plasma can be formed by collision of a high temperature plasma and a molecular cloud in the SNR which is approximated as a nearly collisionless plasma. Conversely, if this phenomenon can be theoretically shown, X-ray observation in addition to gamma rays will prove that the shock waves and molecular clouds are actually colliding. We performed one-dimensional three-fluid calculation to solve the collision between SNR and H_{I} gas as the first step to clarify the interaction between the shock wave and the molecular cloud. By the calculation, we are going to discuss the ionization state of ions in high temperature plasma that collides with H_{I} gas.

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Twenty-seven years of Nobeyama Radioheliograph: Contribution to space weather/climate researches

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Nobeyama Radioheliograph (NoRH) is a radio interferometer specially designed to observe the full Sun. NoRH started its scientific operation in 1992 with a single frequency of 17 GHz and then, 34 GHz capability was added in 1995. NoRH consists of eighty-four antennas with a diameter of 80 cm, installed along a T-shape baseline (North - South: 250 m, East - West: 500 m). The spatial resolution is about 10 arcseconds and 5 arcseconds in 17 GHz and 34 GHz, respectively. The time resolution is 1 second in quiet time and 0.1 second during a solar flare. NoRH continuously observes the sun for about eight hours (22:45 - 6:30 UT) every day. The National Astronomical Observatory of Japan had operated NoRH from 1992. It is currently operated by the Institute for Space-Earth Environmental Research; ISEE, Nagoya University as a representative of the International Consortium for the Continued Operation of Nobeyama Raidoheliograph (ICCON; https://hinode.isee.nagoya-u.ac.jp/ICCON/). NoRH has contributed extensively to the study on active Sun and quiet Sun by observing a number of phenomena such as flares, prominence eruptions, coronal holes, sunspots, and the polar brightening over three solar cycles.

NoRH detected more than 4,000 solar flares since 1992. It provided us a lot of scientific results on solar flares. In 1990s, most of NoRH results were produced through the corroborative researches with Yohkoh. It was revealed where the energy-release and particle acceleration take place in impulsive flares. The coronal magnetic structure observed with Soft X-ray Telescope (SXT) on board Yohkoh played an important role for this kind of researches. Of course, the simultaneous observation with Hard X-ray Telescope (HXT) on board Yohkoh was a great help to understand the behavior (acceleration/transport/loss) of high-energy electrons. After 2002, NoRH collaborated with RHESSI, Hinode, SDO and so forth. More detailed discussions on particle acceleration were done based on really multi-wavelength observations. In this situation, NoRH provides the information of accelerated electrons in the higher energy range from a few hundred keV to a few MeV. Also microwave emissions contain the information of the pitch-angle distribution of accelerated electrons. Thanks to these two characteristics, valuable researches using NoRH have been carried on.

In this presentation, we briefly review the scientific results of NoRH on solar flares and on space weather/climate researches during its continuous observations in these 27 years.

Nobeyama Radioheliograph

Kinetic analysis of the interaction between high temperature plasma and low temperature gas

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When a massive star causes a supernova explosion, the outer layer of the massive star blown off at supersonic velocity collides with the surrounding interstellar medium (ISM) and generates a shock wave, which sweeps and collects the ISM. Shock creates a super-high temperature object called Supernova Remnant (SNR). The energy given to the interstellar medium by the SNR is very high, so understanding of the interaction between the SNR and the surrounding ISM is important. The Crab Nebula is one of the SNRs. It has a pulsar at its center, so that its internal temperature is as high as 10 TeV ($\sim 10^{18}$ K). There are still many puzzling problems about the interaction between this SNR and ISM. For example, recent observations show that some hydrogen molecular clouds (emission line temperature $\sim$2800 K) exist in the ultra-high temperature region of the crab nebula ([1]). The detailed physical process of the interaction between the high temperature plasma and the molecular clouds is still unclear, and in particular, the mechanism to prevent the dissociation of the molecular cloud in contact with the high temperature plasma and the heat conduction from the plasma to the molecular cloud are not fully understood yet([2]). Therefore, in this study, we analyze the interaction between the high temperature plasma and the low temperature molecular cloud in detail using the kinetic theory without fluid approximation, and describe the dissipation phenomenon between the plasma and the low temperature gas in detailed. The goal is to understand the evolution of the velocity distribution function of plasma and gas constituent particles using analytical and numerical methods, and to derive the heat transfer coefficient between plasma and gas. We describe the actual transition to the actual relaxation state. Our findings can be useful in the investigation of interaction of multiple media with very different temperature ubiquitously found in the universe.

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Construction of Solar Flare Emission Spectral Prediction Model

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When solar flare occurs, electromagnetic waves such as microwave to gamma ray are observed. Among these emissions, EUV and X-ray emissions greatly affect to the solar-terrestrial environment especially for total electron content (TEC) in ionosphere. To predicting this affect from flare emissions, we are trying to construct the solar flare EUV emission spectra prediction model. To construct a solar flare EUV emission spectrum prediction model based on the physics of flare, we are searching for the physical parameters which characterize solar flare emission spectra.
In this study, we examined 53 flare events larger than M3-class from the Hinode flare catalogue [1], which were simultaneously observed with the SDO/EVE MEGS-A. As a result, we found that the "GOES soft X-ray peak flux" were well correlated with the "EUV peak intensity" for all Fe lines. We also found the good relationship for the duration of flare emissions. Moreover, we found that hotter lines peaked earlier than cooler lines. From these results from statistical researches, we determined that the EUV emission can be explained by X-ray emission.
We also examined geometrical features of flare ribbons for 32 flare events observed by SDO/AIA, in order to consider which parameter was strongly effect to the time evolution of solar flares. As a result, we found that "flare emission duration" were correlated with "distance between two ribbons" and "ribbon length", and ribbon distance showed better correlation than ribbon length. Therefore, it can be estimated that flare duration is mainly correlated with flare loop length. Then, we performed numerical simulations using observational parameters obtained above statistical results. In this calculation, we used numerical model that can be reproduced the plasma conditions in flare loop [2]. In this paper, we show some results of numerical simulations, and will discuss which parameters strongly control the solar flare EUV emission spectra by comparing with observed data.

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Cloud-cloud collisions in a foot point of a magnetic flotation loop in the Galactic Center

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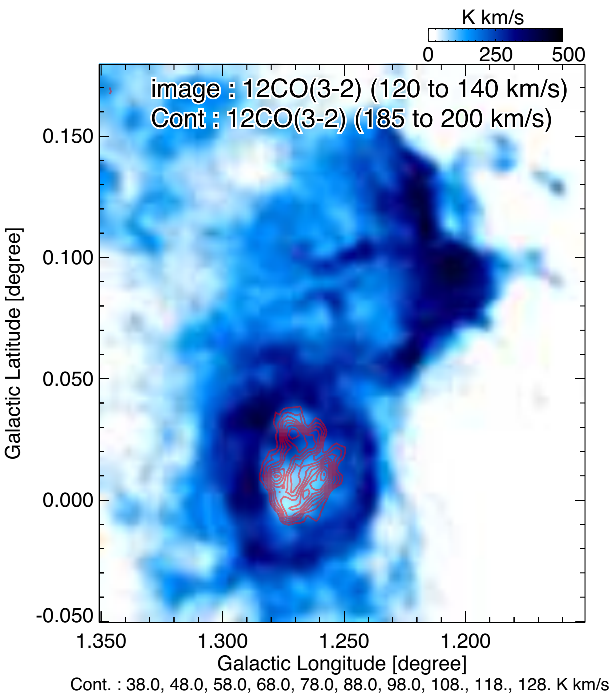

Figure 1: Integrated intensity distribution of the two colliding clouds.

The central a few hundred pc of the Galaxy contains ∼10 % of the entire molecular clouds and hence it is natural to expect clouds in this region to collide with each other frequently . To elucidate this, we performed analyses of three dimensional data of molecular gas, consisting of position-posion-velocity, and found that collisions frequently occur in foot points of molecular loops and consequently enlarge the velocity dispersions of the colliding clouds (Enokiya et al. 2019 submitted). We here show multiple collisions occurring in the L1.3 molecular complex in the Galactic Center (GC). The L1.3 molecular complex is known as the region with extremely large velocity width of ∼100 km s^{-1}. We first classified molecular clouds in this complex by their velocities by using an intensity-weighted velocity distribution map. From this map, we discovered a few pairs of clouds that show completely complementary distribution , which is one of the evidence of the cloud collision (see Figure 1). We also discovered a loop-shaped molecular cloud and found that the colliding clouds are located in a foot point of the loop. We interpret above results as a following scenario: The strong magnetic field of the GC create the magnetic loop through the Parker instability like solar prominences[1]. This loop is accompanied by molecular gas because the fields are frozen into the gas in the condition of the GC[2]. The molecular clouds slided down along the field line by gravity and collided clouds in the foot point. This loop-induced cloud collision model possibly explain the long-time mystery of large velocity dispersions seen in the GC clouds.

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Estimates of Solar Coronal Magnetic Fields with Full Stokes Observations of the Sun using LOFAR

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Corona, the outermost layer of the Sun, is believed to permeate from a heliocentric distance of 1.01 $R_{\odot}$ to more than 1 AU. Being highly tenuous plasma medium, it harbours large scale structures, as multi-frequency observations reveal. One of the most common signatures of any flicker on the Sun is known as solar type III radio bursts. These bursts are an important diagnostic tool to understand the acceleration of non-thermal electron beams along the coronal magnetic field lines. Using the interferometric and beam formed capabilities of LOw Frequency ARray (LOFAR), we analysed a group of type III radio bursts observed between 80-20 MHz, on 30 March 2018. Taking advantage of the high spectral, temporal and spatial resolution of LOFAR, we were able to distinguish five different trajectories of propagation of the electron beams in the type III group. Using full Stokes observations (frequency and time resolution of 10 ms and 12 kHz, respectively) by the simultaneous beam formed LOFAR observations, we estimated the coronal magnetic field along these five electron beam trajectories. This was done by calculating the degree of circular polarisation of the harmonic plasma emission from the type III bursts. The methods and results will be discussed in this talk.

A Brief Introduction of AWs and KAWs in Plasma

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Alfv´en Waves (AWs) covering shear and compressible AWs (also called magnetosonic waves) are the basic low-frequency wave modes in inhomogeneous magnetized plasmas and prevailing in various plasma environments from laboratory to astronomy. As an important way of energy transportion among different dynamical regions in magnetohydrodynamics (MHD), AWs entered the field of researchers' visions and had been an extremely popular subject since 1940s. By carrying energy from the photosphere to heat up the corona and the solar wind, AWs successfully solves the coronal heating problem [1]. Therefore Hannes Alfvén received the 1970 Nobel Prize in Physics for the discovery of AWs.

Kinetic Alfv´en Waves (KAWs) were proposed by Chen and Hasegawa in studies on the heating of laboratory and space plasmas in the 1970's and considered to be a dispersive Alfv´en waves with a short perpendicular wavelength comparable to microscopic kinematic scales of particles, such as the ion (or the ion-acoustic) gyroradius and the electron inertial length, but a parallel wavelength longer than the ion inertial length because of their low frequencies below the ion cyclotron frequency [2]. Despite of the basic properties of AWs, such as the quasi-parallel propagation of the wave group velocity, KAWs possess new characteristics which is contributed to kinetic effects due to the short-wavelength modification, including the nonzero electric field parallel to the steady magnetic field and the motion of ions in the plane perpendicular to the steady magnetic field considerably deviating from the Larmor gyrocircle motion. Those make KAWs capable of field-aligned accelerating or heating electrons and effective exchange of the cross-field energy between waves and ions .

KAWs subtotally explain the formation of field-aligned filamentous structures in a low-β plasma environment whose field-aligned scale of the inhomogeneity is much larger than the cross-field scale because of the strong anisotropy of the motion that the strong ambient magnetic field inhibits the averaged motion of charged particles across the field lines due to the bound gyrocircle motion, while along the field lines the particles are free to move [3].

Anyway, whatever in laboratory, space, and astrophysical plasmas, it's no doubt that KAWs have broad application prospects in the future survey, such as the dissipation of solar wind turbulence, the microscopic physics of magnetic reconnection processes and so on.

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Investigation of the parallel dynamics to determine poloidal inhomogeneity in a tokamak

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In this abstract, we investigate the particle parallel dynamics in a tokamak, which could be useful to study the two-dimensional (radial, poloidal) evolution of plasma density and temperature in a transport time scale. While the plasma transport in tokamak edge is likely to be calculated by Braginskii collisional fluid equation in two-dimensions, the core plasma is likely to be described by flux-surface averaged fluxes in one dimension. However, the poloidal inhomogeneity in the core can be non-negligible in the presence of significant inhomogeneous external source (e.g. RF waves, NBI) or impurity.
First, we revisited the well-known Springer Spin-Up (SSU) problem [1] driven by the poloidally inhomogeneous radial particle flux with extra constraints. The growth rate of spin-up is determined by inhomogeneity of magnetic field in a flux surface. To saturate the spin-up, the viscous force is added in our study. The relation between parallel flow and viscous force is given by neoclassical viscosity, which is calculated using a drift-kinetic code, PERFECT [2], in every collisional regime. Although neoclassical viscosity saturates the spin-up, the poloidal inhomogeneity cannot be suppressed because of the weak coupling between poloidal modes. The poloidal spreading may require capturing the feature of geodesic acoustic modes (GAM) [3], which include the parallel electric field and finite orbit width effect for the poloidal coupling.

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A New Online Database of Filament

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The solar filaments observed in the Hα line in the solar chromospheres are one of the basic indices of solar activity[1]. On the one hand, they are associated with flares and coronal mass ejections (CMEs) [2][3], which are the major driving sources of hazardous space weather. The understanding of solar filaments becomes crucial in space weather research. Increasing observational evidence suggests that filament eruptions, flares, and CMEs are different manifestations of one physical process at different evolutionary stages [4] [5]. In order to gain a better understanding of CMEs and advance our forecast capabilities, it is essential to identify early manifestations of CMEs such as filament eruptions and flares [6]. On the other hand, long term filament data is needed by these studies, for examples, the long-term variation of the statistical properties of filament that carry important information on the magnetic signature of the solar cycle, polar crown filament demonstrates the interface between new and old solar cycle, the investigation of the possible unusual behaviour of cycle 23 compare to the other previous cycles, the possible changes of efficiency in the dynamo may be probed with study, the understand of the global magnetic topology with large scale structure of solar eruptions, and so on. Long-term filament data can be efficiently used as a proxy for magnetic activity of the Sun. Additionally, the study of the occurrence of filaments provides useful insight into the distribution of photospheric fields on the solar surface, and their evolution, and help in the understanding of the nature of the Sun's magnetic field, flare and CMEs. Systematically analyze of long term data are useful for understand the cycle variation of solar activities, emphasizing on the filaments and their eruptions. It is also useful for the understanding of the solar source of eruptions. Several features of solar filaments might be meaningful whatever for forecast or study, such as the location, size, length, average wide, tilt angle, and number and direction of barbs, etc. A systematic cataloguing procedure for filaments is not in place. So a new online filament database for 100 years is being constructed for the international scientific community. Original data is from 5 observatories in the world. These data provide a temporal continuity and complementarity partly. It has query and statistics functions for these physical features, and visualization function of their statistical results. Meanwhile there are some data products of different levels, for example, the evolution films of solar activities, binary images of filament boundary, enhanced Hα images for the past 9 cycles in order to meet different needs of the international scientific community. The database and these data products will be useful to understanding these problems mentioned above and other physics problems.

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Subcritical magneto-hydrodynamic instabilities

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Linear stability analysis is a powerful tool but it is only valid when the amplitude of the perturbation is infinitesimally small. In recent years purely hydrodynamic researchers uncovered that subcritical transition to turbulence in always linearly stable flows (e.g. plane Couette flow, pipe flow) is associated with the finite amplitude invariant solutions of the governing equations. In this talk we shall extend the subcritical transition theory in plane Couette flow to magneto-hydrodynamic (MHD) states. In particular, a large Reynolds number matched asymptotic expansion is developed for nonlinear 3D MHD states driven by a shear. The theory has emerged out of a nice combination of the vortex-wave interaction theory by Hall & Smith (1991) and the resonant absorption theories developed in solar physics community (e.g. Sakurai et al. 1991). The dynamos are self-sustained, in the sense that they are maintained without any linear instability mechanism of the laminar base flow.

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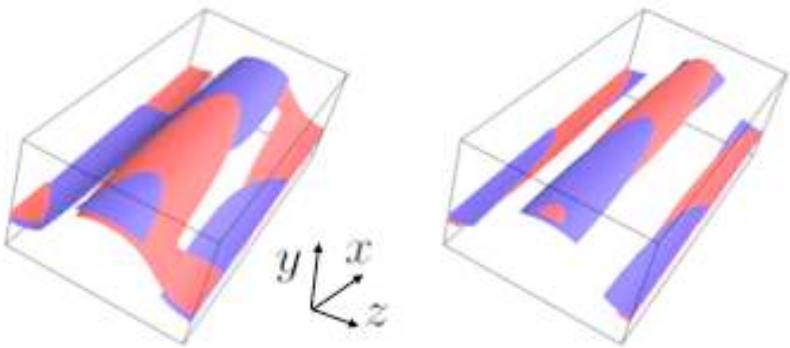

Figure 1: 50% streamwise vorticity (left) and current (right) of the self-sustained shear driven dynamo in plane Couette flow (the basic flow is u=y). The vortex/current sheet appears at the resonant position.

Experimental research on turbulent transport in non-uniform turbulence field

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Non-isotropic nature is often observed in turbulence with mean-flow and rotation, etc., and understanding macroscopic properties of such turbulence is a common issue in various research fields.

When temperature gradient ∇T exists in a system, Brownian particles are transported in the direction of $-\nabla T$, and resultant density gradient is formed in the system. This phenomenon is called the Soret effect. In this study, we investigate whether the gradient of turbulent intensity can drive particle transport or not, in other words, the occurrence of similar phenomena to the Soret effect in turbulence. This means that the non-uniform turbulent intensity creates a gradient of the diffusion coefficient and the resultant density gradient is formed.

Electroconvection turbulence driven by applying AC voltage to liquid crystal cell was used in this experiment. The intensity of electroconvection turbulence can be controlled by $\varepsilon = (V^2 - V_c^2)/V_c^2$, where V is applied voltage, V_c is critical voltage at which electroconvection starts. Recently, we observed an excitation of mean-flow in electroconvection turbulence, when the gradient of ε was produced by control of temperature gradient in the cell as shown in the Fig.1. In the presentation, we will discuss on motivation, experimental setup, preliminary results such as excitation of mean-flow and transport property of spatially non-uniform turbulence, etc.

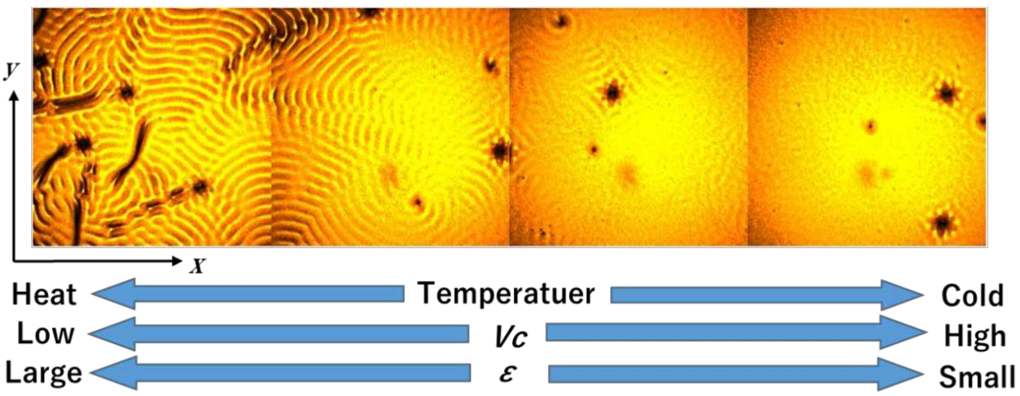

Fig.1 : An electroconvection driven in the liquid crystal cell with temperature gradient.