National Institute of Natural Sciences

National Institute for Fusion Science

NIFS Peer Review Reports in FY2019

March, 2020

National Institute for Fusion Science

Advisory Committee External Peer Review Committee

Contents

Chapter 1 Background

The National Institute for Fusion Science (below as NIFS) was established in 1989 as an inter-university research institute, and utilizes the Large Helical Device (below as LHD) as the principal device to advance fusion research in universities in Japan.

The LHD, which was planned by bearing the support and the expectations of the fusion community, has the special characteristic of producing the heliotron-type magnetic field, which is an idea unique to Japan. In addition to generating high-performance helical-type plasma through high-power heating, NIFS is advancing with experimental research that aims to clarify physical and technological issues for realizing the toroidal magnetic field confinement fusion reactor. On the other hand, parallel with this, in analyses of fusion plasmas having fundamental complexities, theoretical research that uses large-scale simulations is essential. For that reason, a supercomputer for exclusive use was introduced at NIFS. We are advancing with leading-edge research by making this supercomputer at NIFS available for use to fusion theory researchers in Japan through collaborative research. Moreover, since 2010, in order to further strengthen the centripetal power of NIFS as a Center of Excellence (below as COE) in the field of plasma and fusion research we have organized three research projects, these being LHD, theory and simulation, and reactor engineering. Looking forward toward achieving the fusion reactor, initiated research programs will integrate these research results.

In addition to having revised the research structure within NIFS and having placed all research staff in one research department, by establishing a research system that enables participation by free will in research projects and has enabled easier cooperation in the three projects of LHD, theory and simulation, and reactor engineering than in the past, we are increasingly able to respond resourcefully to new topics.

In this period, there have been changes to the structure of the domestic academic research system. Since 2004, NIFS has been a research institute under the Inter-University Research Institute Corporation National Institutes of Natural Sciences (below as NINS) for enhancing further the domestic research collaboration. Upon becoming an inter-university research corporation, a system for mid-term goals and mid-term planning spanning six years was introduced, and a system of annual evaluations regarding the progress, too, was introduced. This annual evaluation focuses primarily upon administrative management. However, at NIFS it has been determined that receiving external evaluations of research results is important. Under the NIFS Advisory Committee, each year an External Peer Review Committee is organized and the members evaluate the research. The topics of evaluation are determined by the Advisory Committee. The evaluation is undertaken by the members of the External Peer Review Committee, which is composed of experts who are external members of the Advisory Committee and external experts who are appropriate for evaluating the topics. The External Evaluation Committee submits its evaluation results to the Advisory Committee. Then, NIFS, together with making the results public by uploading that information to the NIFS homepage, utilizes this information to improve research activities in the following years.

The topics for evaluation for the External Peer Review Committee are discussed and decided upon by the Advisory Committee, and those topics for evaluation differ each year. Most recently, in 2016 Collaborative Research, in 2017 the Reactor Engineering Research Project, and in 2018 Large Helical Device Project were topics evaluated by external reviewers. This year, 2019, the “Numerical Simulation Reactor Research Project” was selected and reviewed by the external examiners.

As external members of the External Peer Review Committee there were ten external members from the Advisory Committee and three members from foreign countries. Further, there were two experts from outside NIFS and one expert from abroad. Thus was the External Peer Review Committee composed, and thereby the evaluation was undertaken.

The first meeting of the External Peer Review Committee including the Experts’ Committee was convened on October 23, 2019. The Committee discussed the process for moving forward with this fiscal year’s external peer review, and decided upon the perspective of the evaluation. On November 23, 2019, the second meeting of the External Peer Review Committee and Experts’ Committee was held. From NIFS was provided a detailed explanation that utilized documents from the material of viewgraphs and reports based on the perspectives (see the documents section). A question-and-answer session also was held. Subsequently, the third meeting of the External Peer Review Committee and the Experts’ Committee was held on January 28, 2020. Together with holding another question and answer session with NIFS, evaluation work based on the topics of the evaluation and the coordination of the evaluation work were undertaken. We compiled the external peer review report (draft) based upon the discussions to this point, and further discussions were held by electronic mail. Upon confirmation and examination by the External Peer Review Committee and the Experts’ Committee, we compiled the final report. Please see Reference Material 4 for the meeting schedule of the External Peer Review Committee and the Experts’ Committee.

Moreover, in the external evaluation regarding “Numerical Simulation Reactor Research Project” which was implemented this fiscal year, the perspectives for the evaluation were determined as follows. The perspectives for the evaluation are considered indispensable in the evaluation of the “Numerical Simulation Reactor Research Project” promoted by NIFS which NINS decided upon in the mid-term planning. These perspectives are the basis of the evaluation of achievements and the evaluation of the level of research.

Further, we have consulted the following points in the evaluation which are based upon the recommendations implemented in the External Peer Review Report of the “Numerical Simulation Reactor Research Project” in 2015.

Evaluation items regarding the Numerical Simulation Reactor Research Project - FY2019 External Peer Review

The items mentioned hereinafter consist of all the aspects that are indispensable in evaluating the performance of NIFS's Numerical Simulation Reactor Research Project (NSRP) under the mid-term plan issued by NIFS's parental body, the National Institutes of Natural Science. Reviewers will assess the levels of goal attainment and scientific quality.

The following proposals from the previous review regarding the NSRP in FY2016 are taken into account in the evaluation this time.

1) It is necessary to show clearly the final goal of the NSRP, share it with each research group, strengthen the check system for the progress of the research group's goal, and pay attention to the management in order to produce the synergy effect by collaboration between research groups.
2) The research plan and system should be speedily improved and strengthened by being constantly aware of combining and integrating the developed elements with a roadmap in a view for finally completing the integration.
3) Regarding the Plasma Simulator and the improvement of the related research environment, it is hoped to check the progress of each group in the entire project and take it into account for making plans suitable for step-by-step goals. In particular, regarding the supercomputer system which is indispensable for the integration, it is recommended to actively promote the installation of a higher performance supercomputer toward the future for making contributions to further the development of plasma and fusion research.
4) It is recommended to maintain and develop the research system in which researchers contribute to both project promotion and scientific progress. In addition, it is hoped to improve competitiveness, which enables information dissemination to other research fields, and contributes to the creation of new academic fields through interdisciplinary activities.
5) For the purpose of maintaining high-level simulation research activities necessary for developing the fusion reactor, it is recommended to systematically commit to human resource development with universities, and further enhance both quality and quantity.

Evaluation items in FY2019 External Peer Review

1. **Development of research plan, system, and environment**

(1) Does the Numerical Simulation Reactor Research Project (NSRP) appropriately set the goal and plan including the roadmap for construction of the Numerical Simulation Reactor? Are they properly discussed for accomplishing the third midterm target and plan?

(2) Does the research system function appropriately in accomplishing the objectives of the NSRP with attention to the management of step-by-step progress, research collaboration, and integration?

(3) Is the environment of the "Plasma Simulator" system and its related research appropriately developed and effectively utilized accordingly to the research plan? Is the installation of a higher performance supercomputer properly planned?

2. Research achievements

Does the NSRP produce high-level achievements in accordance with international standards for the following research areas described in the third midterm goal and plan by promoting theory and computer simulation research utilizing the Plasma Simulator?

(1) Construction of the Numerical Simulation Reactor, Validation and improvement of simulation codes through comparison to experimental results

(2) Academic systematization of fusion science and related science and engineering

(3) Are research achievements steadily made according to the plan of the NSRP?

3. Promotion of cooperation and collaboration

(1) Is collaboration research with universities based on theory and simulation research appropriately promoted? Does it contribute to the progress of the NSRP?

(2) Does the NSRP contribute to enhancing functions of universities and institutes as the center of excellence for fusion plasma simulation? Does the NSRP commit to the promotion of interdisciplinary collaboration and research?

(3) Does the NSRP contribute to international cooperation including ITER, BA activities, and others through international collaboration activities?

4. Human resources development

(1) Does the NSRP contribute to the development of human resources required for maintaining high-level simulation research activities toward the future?

5. Future plan

(1) Is the future research plan suitable for progressing toward the goal of the NSRP? Does it also contribute to establishing the future plan of the National Institute for Fusion Science?

Chapter 2 Summary of the Evaluation, and Recommendation

We summarize the key points of the evaluation, and report in writing the recommendation regarding promotion of the Numerical Simulation Reactor Research Project.

［１］ Summary of the Evaluation

1. Development of research plan, system, and environment

（1） Does the Numerical Simulation Reactor Research Project (NSRP) appropriately set the goal and plan including the roadmap for construction of the Numerical Simulation Reactor? Are they properly discussed for accomplishing the third midterm target and plan?

The Numerical Simulation Reactor Research Project (NSRP) is appropriately positioned and promoted as one of the major research projects of NIFS in the third mid-term target and plan. The NSRP plays an important role not only in research of helical systems represented by LHD but also in research of tokamaks from the viewpoint of interactive and synergistic studies. This is a distinctive research project that aims at high-precision and high-resolution modeling based on experimental data. It is hoped that the NSRP will reaffirm its significance and contribute to the achievement of the objectives as well as the advancement of science while succeeding and developing the history of NIFS, which has contributed deeply to the progress in a wide range of simulation science.

Since this is a long-term plan, it will be necessary to reexamine the roadmap for the realization of the Numerical Simulation Reactor and flexibly modify the research plan toward integration of developed simulation codes in accordance with results of experimental research and scientific progress. It is desirable to pursue innovation of simulation research and aim for leadership in academic research.

（2） Does the research system function appropriately in accomplishing the objectives of the NSRP with attention to the management of step-by-step progress, research collaboration, and integration?

It is highly evaluated that the NSRP sets up appropriate milestones, checks the step-by-step progress, and organizes eight task groups to manage research collaboration and integration. Constructing a collaborative research system that includes outside researchers and holding management meetings across the task groups, smooth information exchange is enhanced and a framework that conducts the project with a common awareness is established. Coordination with other projects is being promoted appropriately, and the research system is generally functioning effectively.

However, since the bottom-up research promotion system may not work effectively in terms of integration, it is necessary to take appropriate measures while viewing the entire research plan. It is hoped that academic research will be further advanced and lead to better achievements by enhancing organized collaboration between the task groups and making effective use of human resources.

(3) Is the environment of the "Plasma Simulator" system and its related research appropriately developed and effectively utilized according to the research plan? Is the installation of a higher performance supercomputer properly planned?

The environment of the Plasma Simulator and its related research has been properly developed, updated, and maintained in accordance with the research plan, and has been effectively used at a high utilization rate. Not only the hardware environment but also the software support activities for users are implemented, and an excellent environment that supports fusion theory and simulation research has been constructed. It is an important resource for activating collaborative research with outside organizations and is expected to be used even more effectively in maintaining the competitiveness of Japan's simulation science.

In addition, it is necessary to clarify the position of the NSRP in the field of simulation science, and to strategically promote the formulation and the execution of the research plan.

2. Research achievements

Does the NSRP produce high-level achievements in accordance with international standards for the following research areas described in the third midterm goal and plan by promoting theory and computer simulation research utilizing the Plasma Simulator?

(1) Construction of the Numerical Simulation Reactor, validation and improvement of simulation codes through comparison to experimental results

Many research results have been created and outstanding progress has been made by using the codes developed in the NSRP, and also by comparing simulation results with experimental results. The simulation codes have been improved and partially integrated, contributing to the LHD Project. Original and excellent research results have been achieved at each hierarchical level, and the sophistication of the codes is progressing smoothly. The broad development is highly evaluated although it will be necessary to consider focusing human resources because they cannot be sufficiently allocated to all themes. It is hoped that the NSRP will continue research for elucidation of the essential physics such as multi-scale coupling in the future.

（2） Academic systematization of fusion science and related science and engineering

The NSRP is appropriately positioned in the third mid-term target and plan, and it can be evaluated as contributing to the academic systematization of fusion science and related sciences and technology. In particular, it is highly evaluated that the NSRP disseminates the research achievements to academic societies through presentations of high-level results, actively publishing textbooks and review papers, and engaging in enlightenment activities. Overall, it is evaluated as progressing.

It is desired that the NSRP will actively pursue research subjects of high academic value common to other fields, such as multi-scale simulation. The goal of the NSRP aiming at integration itself can be said to be academic systemization. Further efforts to achieve this goal are expected.

（3） Are research achievements steadily made according to the plan of the NSRP?

The resources such as the Plasma Simulator have been effectively utilized to achieve numerous results in the theory and simulation research while systematically developing and extending many simulation codes required to promote the NSRP. In particular, the Plasma Simulator is utilized at a high rate for collaborative research, and it functions as a core project of the researchers' community. The research achievements are also presented and disseminated in a form that is easily visible to society, and steady progress is being made in research. The NSRP is also actively working on application of the codes, such as designing a new device for the future plan, and it is evaluated that the past research has been bearing fruit.

On the other hand, there are differences in the progress of research and the number of presentations among the research groups, and it is feared that a new academic challenge will not be created if it falls into a mission research promotion system with limited subjects. It is hoped that, with a view to expanding into other fields, the NSRP always maintains a challenging spirit for unexplored issues, which will lead to further development of the project and the development of new academic fields.

3. Promotion of cooperation and collaboration

(1) Is collaboration research with universities based on theory and simulation research appropriately promoted? Does it contribute to the progress of the NSRP?

The NSRP promotes collaboration with universities nationwide, accepts about seventy collaborative researches with nearly two hundred collaborators from inside and outside NIFS, holds Plasma Simulator Symposia for active discussion and information exchange with domestic researchers, and contributes to activating the field of theory and simulation. Thus, it can be evaluated that collaborative research with universities based on the theory and simulation research is being carried out appropriately.

The role of NIFS as a center of collaborative research is critical. In addition to promoting the projects, it is expected to play an active and leading role in relationships with other institutes and various fields. It will also be useful in the future to carry out quantitative evaluations such as counting the number of collaborators in the eight research groups organized in the NSRP.

(2) Does the NSRP contribute to enhancing functions of universities and institutes as the center of excellence for fusion plasma simulation? Does the NSRP commit to the promotion of interdisciplinary collaboration and research?

The NSRP has achieved results in a wide range of research fields by conducting collaborative research with many universities and research institutes. In addition to applying the simulation codes developed by NIFS for actively supporting experimental research carried out at universities, the NSRP holds many workshops every year and plays a central role in exchanging information among researchers in the universities. It is highly evaluated as contributing to the enhancement of the functions of universities and institutes as a center for fusion plasma simulation. Furthermore, it can be evaluated that the NSRP is committing to collaboration with the astronomy field in the NINS, interdisciplinary collaboration such as molecular dynamics simulation on DNA damage, and promotion of research for fusion of different fields.

It is expected that the NSRP will increase competitiveness against other fields and further promote international and academically valuable collaborations while using results obtained from the construction of the Numerical Simulation Reactor to found a basis for building a universal science.

(3) Does the NSRP contribute to international cooperation including ITER, BA activities, and others through international collaboration activities?

It is highly evaluated that the NSRP actively contributes to the ITER Project, BA activities and a wide range of international cooperation such as Japan-US, Japan-EU collaborations, Japan-China-Korea Foresight Program, International Tokamak Physics Activity (ITPA), ITER Integrated Modelling Expert Group (IMEG), and IFERC Project.

On the other hand, in order to spread the excellent codes developed in NIFS as international standards, it is necessary to further enhance international collaboration and systematically carry out dissemination activities. It is hoped that the NSRP will actively contribute to making overall policies and plans for the ITER Project and BA activities in the future.

[4] Human resources development

Does the NSRP contribute to the development of human resources required for maintaining high-level simulation research activities toward the future?

The NSRP is accepting graduate students from universities such as the Graduate University for Advanced Studies and Nagoya University, and developing young human resources through cooperation with Asian Winter Schools and high schools designated as SSH. It can be highly evaluated that the NSRP contributes to the nurture of young domestic and foreign researchers in addition to young staff members at NIFS through the achievement of developing multi-scale simulation codes systematically to date.

On the other hand, it is desirable to develop an organizational strategy for human resource development, including career path formation, and to promote personnel plans and personnel exchanges with a view to continued development in the future.

[5] Future plan

Is the future research plan suitable for progressing toward the goal of the NSRP? Does it also contribute to establishing the future plan of the National Institute for Fusion Science?

Research on the validity and applicability of theoretical and numerical models has been steadily conducted so far and roadmaps for each of the eight task groups are formulated for advancing research toward the goal of the NSRP. In addition, it is highly evaluated that the NSRP plays a major role in establishing the future plan of NIFS, including the next-generation device.

On the other hand, it is necessary to further develop future plans and set research goals by clarifying development issues for the realization of the Numerical Simulation Reactor, roadmaps for each task group, and efforts toward the code integration. It is also desirable to actively discuss collaboration among the task groups and experimental projects and to examine top-down promotion regarding the issues required to achieve the goal of the NSRP.

［２］ Recommendations

In the present evaluation, we discussed the Numerical Simulation Reactor Research Project (NSRP) in NIFS. Based upon the contents of the discussion, we describe the recommendations regarding the future plan of the Numerical Simulation Reactor Research Project below.

(1) As one of the major research projects in NIFS, the Numerical Simulation Reactor Project has been conducting distinguished studies and playing an important role in all facets of fusion research. While maintaining and developing the route of research that has contributed to progress in a wide range of simulation sciences, collaborations among the task groups and other institutes should be planned so as to constantly create new research themes based on flexible ideas. It is desired that fulfillment of the management system and allocation of the resources are made based on constant check and evaluation for construction of the Numerical Simulation Reactor.

(2) It is hoped that NIFS will aim for leadership in interdisciplinary research based on the Numerical Simulation Reactor Research, pursuing impactful innovations such as hierarchical integration in the entire field of simulation science.

(3) The simulation science research environment in NIFS is one of the foundations for promoting plasma and nuclear fusion research throughout Japan. It is necessary to plan and implement installation / maintenance of supercomputers and enhancement of the support system at appropriate times in the future, incorporating the opinions of collaborative researchers and institutions.

（4） The role of NIFS as a center of collaborative research is crucial, and its active contribution to strengthening the competitiveness of universities is desired in addition to conducting the project. From the viewpoint of academic systematization, further enhancement of international collaboration and commitment to organized dissemination activities are desired in order to link the achievements in the NSRP to the construction of universal science and make the excellent developed codes be used as international standards.

（5） For continuous development of the research field, it is hoped that personnel planning and personnel exchange will be actively promoted with a view to the future of the Numerical Simulation Reactor Research. Systematic efforts are desired for development of a wide range of human resources in the fields of theory and simulation including career path formation.

Chapter 3　In Closing

Since 2010, in order to further strengthen the centripetal power of NIFS as a COE in the field of plasma and fusion research we have organized three research projects, these being LHD, theory and simulation, and reactor engineering. Looking forward toward achieving the fusion reactor, NIFS has initiated research programs that will integrate these research results. Moreover, the research structure at NIFS was reorganized and all academic researchers have now been placed in one research department. They may now participate in any or all of the three research projects by their choice. Due to this, we anticipate the promotion of links with LHD, theory and simulation, and fusion engineering, and we anticipate being able to respond resourcefully to new topics.

In the NIFS External Peer Review Committee review, in 2016 the Collaborative Research, in 2017 the Reactor Engineering Research Project, and in 2018 the LHD Project were evaluated. Thus, in this current year of 2019 the Advisory Committee undertook an external evaluation that focused on "The Numerical Simulation Reactor Research Project." The External Peer Review Committee was composed of 10 members of the Advisory Committee outside of NIFS and three members from abroad, and, as the experts, three members outside of NIFS.

Evaluation items in FY2019 External Peer Review

1. Development of research plan, system, and environment

(1) Does the Numerical Simulation Reactor Research Project (NSRP) appropriately set the goal and plan including the roadmap for construction of the Numerical Simulation Reactor? Are they properly discussed for accomplishing the third midterm target and plan?

(2) Does the research system function appropriately in accomplishing the objectives of the NSRP with attention to the management of step-by-step progress, research collaboration, and integration?

(3) Is the environment of the "Plasma Simulator" system and its related research appropriately developed and effectively utilized according to the research plan? Is the installation of a higher performance supercomputer properly planned?

2. Research achievements

Does the NSRP produce high-level achievements in accordance with international standards for the following research areas described in the third midterm goal and plan by promoting theory and computer simulation research utilizing the Plasma Simulator?

(1) Construction of the Numerical Simulation Reactor, Validation and

improvement of simulation codes through comparison to experimental results

(2) Academic systematization of fusion science, related science, and engineering

(3) Are research achievements steadily made according to the plan of the NSRP?

3.Promotion of cooperation and collaboration

(1) Is collaboration research with universities based on theory and simulation research appropriately promoted? Does it contribute to the progress of the NSRP?

(2) Does the NSRP contribute to enhancing functions of universities and institutes as the center of excellence for fusion plasma simulation? Does the NSRP commit to the promotion of interdisciplinary collaboration and research?

(3) Does the NSRP contribute to international cooperation including ITER, BA activities, and others through international collaboration activities?

4.Human resources development

(1) Does the NSRP contribute to the development of human resources required for maintaining high-level simulation research activities toward the future?

5.Future plan

(1) Is the future research plan suitable for progressing toward the goal of the NSRP? Does it also contribute to establishing the future plan of the National Institute for Fusion Science?

The External Peer Review Committee was convened four times from October 2019 through February 2020 including the e-mail discussion committee. Detailed explanations of the evaluation topics were provided from NIFS and active discussions were held. The External Peer Review Committee members summarize evaluation results based on discussion at the committee and submit this report.

As the result of the external evaluation of the “Numerical Simulation Reactor Research Project, (NSRP)” in general, a recommendation of a high evaluation are received for the above evaluation points. Especially, development and improvement of simulation codes toward construction of the Numerical Simulation Reactor are highly evaluated observing the steady progress in which numerous remarkable research results were produced from the organization of task groups. In addition, as one of the major research projects in NIFS, the NSRP has been appropriately developing the simulation research environment including the “Plasma Simulator” and making sufficient efforts to maximize the research achievements. The NSRP have been actively promoting collaboration research, striving for construction of an excellent support system, and making a significant contribution to the academic progress of the entire research community as the Inter-University Research Institute.

It is desired on the other hand that the roadmap for the construction of the Numerical Simulation Reactor is appropriately reviewed according to the research progress, and new scientific subjects are challenged for the further development of the NSRP and pioneering new academic fields. Furthermore, it is hoped that, as a center of collaborative research, the NSRP actively and initiatively conducts high-scholarly-valued studies and takes leadership in academic research while promoting international and interdisciplinary collaborations.

In conclusion, we suggest the following recommendations regarding the future plan of the Numerical Simulation Reactor Research Project (NSRP).

(1) As one of the major research projects in NIFS, the Numerical Simulation Reactor Project has been conducting distinguished studies and playing an important role in the entire fusion research. While maintaining and developing the route for research that has contributed to the progress in a wide range of simulation science, collaborations among the task groups and other institutes should be planned so as to constantly create new research themes based on flexible ideas. It is desired that fulfillment of the management system and allocation of the resources are made based on constant check and evaluation of construction of the Numerical Simulation Reactor.

(2) It is hoped that NIFS will aim for leadership in interdisciplinary research based on the Numerical Simulation Reactor Research, pursuing impactful innovations such as hierarchical integration in the entire field of simulation science.

(3) The simulation science research environment in NIFS is one of the foundations to promote plasma and nuclear fusion research throughout Japan. It is necessary to plan and implement installation / maintenance of supercomputers and enhancement of the support system at appropriate times in the future, incorporating the opinions of collaborative researchers and institutions.

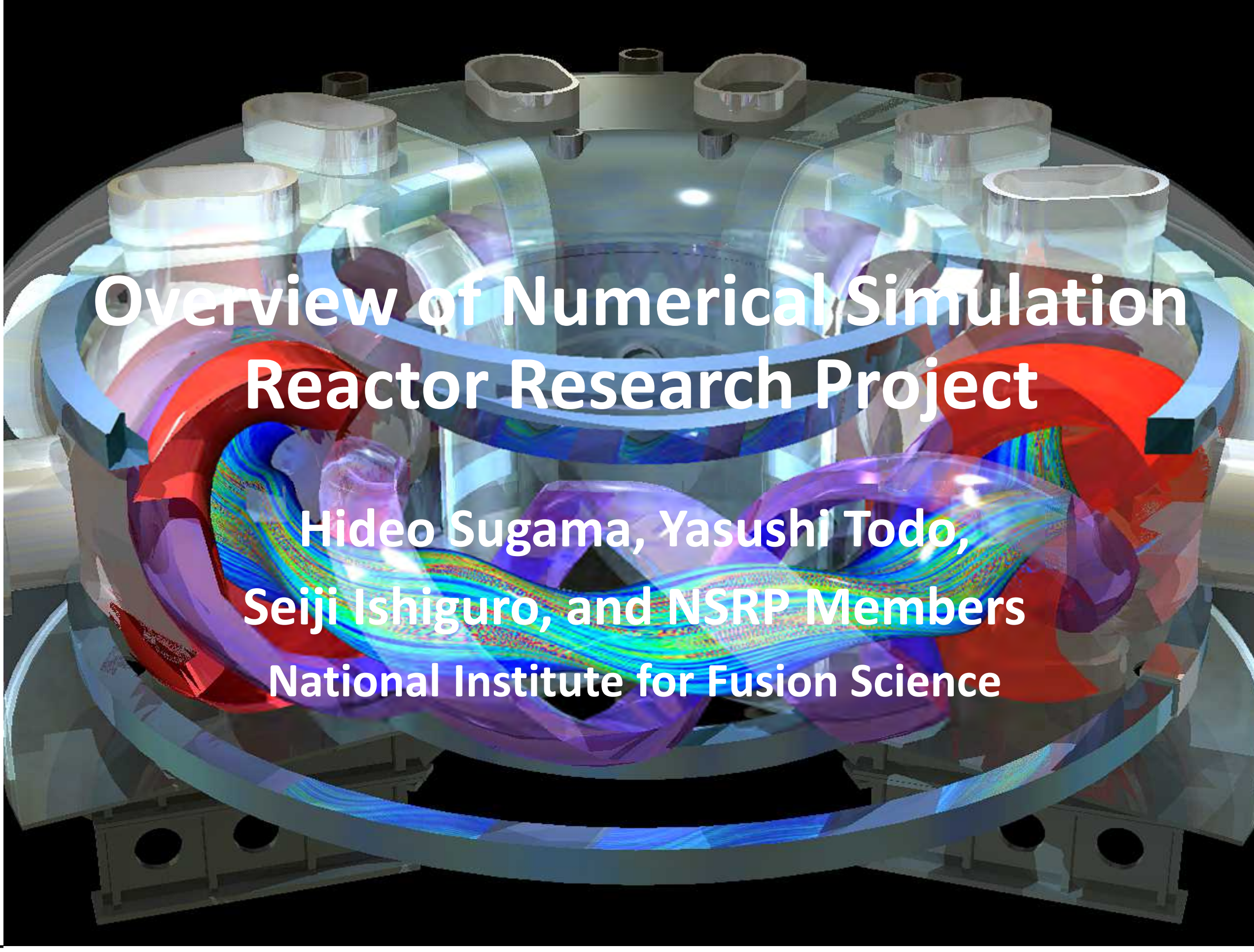
(4) The role of NIFS as a center of collaborative research is crucial, and its active contribution to strengthening the competitiveness of universities is desired in addition to conducting the

project. From the viewpoint of the academic systematization, further enhancement of international collaboration and commitment to organized dissemination activities are desired in order to link the achievements in the NSRP to the construction of universal science and make the excellent developed codes be used as international standards.

(5) For continuous development of the research field, it is hoped that personnel planning and personnel exchange will be actively promoted with a view to the future of the Numerical Simulation Reactor Research. Systematic efforts are desired for development of a wide range of human resources in the field of theory and simulation including career path formation.

Documents

1. 2019 External Peer Review Presentation Materials



Overview of Numerical Simulation Reactor Research Project

Hideo Sugama, Yasushi Todo,
Seiji Ishiguro, and NSRP Members
National Institute for Fusion Science

Outline

1. Research plan, system, and environment
2. Research achievements
3. Promotion of cooperation and collaboration
4. Human resources development
5. Future plans

1. Development of research plan, system and environment

(1) Does the **Numerical Simulation Reactor Research Project (NSRP)** appropriately set the goal and plan including the roadmap for construction of the Numerical Simulation Reactor? Are they properly discussed for accomplishing the third midterm target and plan?

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(3) Is the environment of the "Plasma Simulator" system and its related research appropriately developed and effectively utilized accordingly to the research plan? Is the installation of a higher performance supercomputer properly planned?

Presentation by H. Sugama (1)

2. Research achievements

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(1) Construction of the Numerical Simulation Reactor, Validation and improvement of simulation codes through comparison to experimental results

Presentation by Y. Todo

(2) Academic systematization of fusion science and related science and engineering

Presentation by S. Ishiguro

(3) Are research achievements steadily made according to the plan of the NSRP?

Presentation by H. Sugama (2)

3. Promotion of cooperation and collaborations

(1) Is collaboration research with universities based on theory and simulation research appropriately promoted? Does it contribute to the progress of the NSRP?

(2) Does the NSRP contribute to enhancing functions of universities and institutes as the center of excellence for fusion plasma simulation? Does the NSRP commit to the promotion of interdisciplinary collaboration and research?

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[1]-(1)

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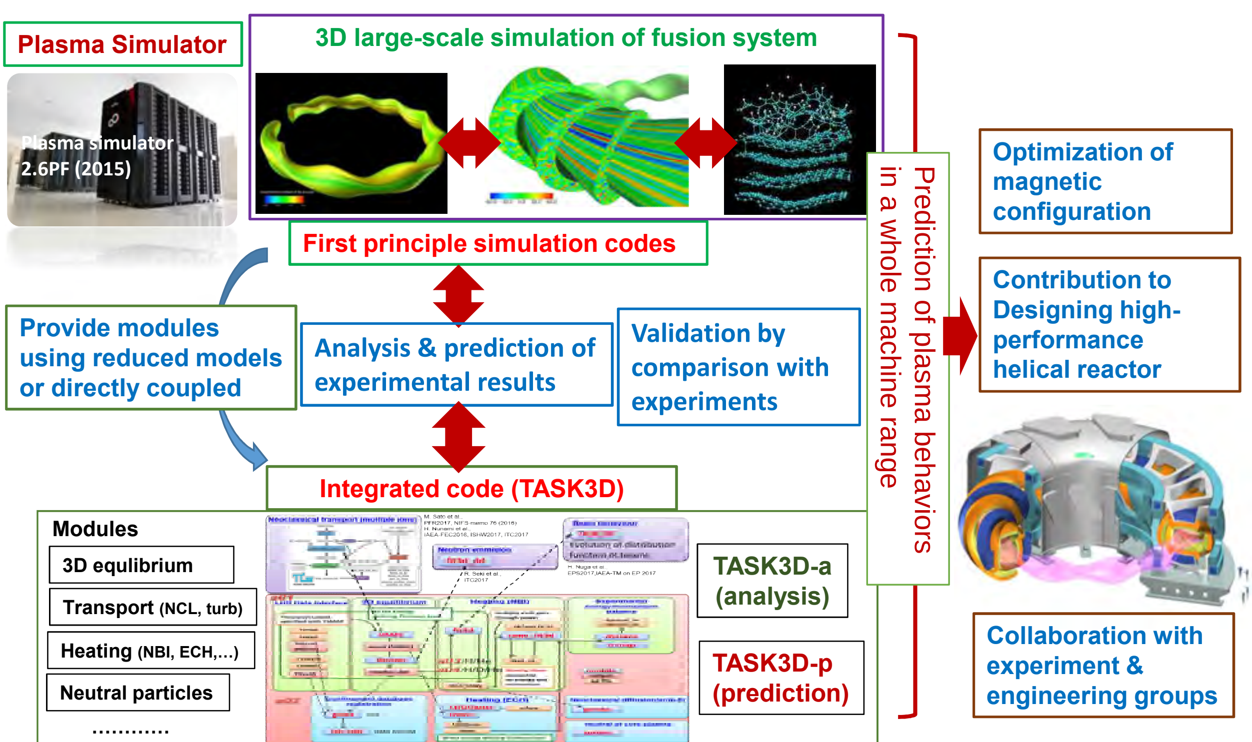
The goal of the NSRP is

to construct the **Numerial Simulation Reactor** (➔ next page) and

to **systematize and develop nuclear fusion science and related science and engineering through collaboration with universities and research institutes** (➔ **third midterm target**) .

Numerical Simulation Reactor

A system of simulation codes to predict behaviors of fusion plasmas over the whole machine range



Third Midterm Target and Plans

Third Midterm Target of NIFS (FY2016-2021)
As a COE of nuclear fusion science research in Japan, NIFS aims to systematize and develop nuclear fusion science and related science and engineering through collaboration with universities and research institutes.
To realize controlled thermonuclear fusion with excellent environmental safety, NIFS promotes joint researches in Japan using a large experimental device and a supercomputer as well as supporting burning plasma experiments through international collaboration.

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Third Midterm Plan of NSRP (FY2016-2021)
[Means to achieve the target related to levels and results of research]
Effectively using the supercomputer system, Plasma Simulator, for construction of the Numerical Simulation Reactor, we advance the researches for the development, the extension, the high precision, and the integration of the simulation codes for the whole device from the core plasma to the peripheral plasma and plasma facing wall.
During FY2019, we improve the performance of the Plasma Simulator more than four times compared to the current system, and optimize various three-dimensional simulation codes for the improved system.
In addition, modeling of turbulent transport in core plasma and the application of the model into the integrated transport code are to be completed by the end of FY2019, and the incorporation of multiple ion species effects into various transport codes is to be done by the end of the third mid-term target period.
Furthermore, by the end of the third mid-term target period, molecular dynamics simulation techniques are developed by improving programs and building new models necessary for evaluating the physical properties of plasma facing materials such as tungsten.
Simultaneously, as supporting research to achieve the above goals, we improve the code accuracy by comparison with the experimental results on the three-dimensional equilibrium, transport, instability and nonlinear evolution of magnetically confined plasmas including LHD plasmas while conducting simulation researches on related basic physics.

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Third Midterm Plan of NIFS (FY2016-2012)
[Means to achieve the target related to contents and levels of joint use and research]
Deuterium plasma experiments using LHD, large-scale simulations using Plasma Simulator, and reactor engineering researches utilizing large test facilities are conducted as advanced joint use and joint research through domestic and international collaborations.
NIFS aims to improve the quality of domestic collaborations and to increase the opportunities for international collaborations.
NIFS contributes to the creation of research results from universities by leading collaborative research using inter-university networks such as interactive joint research as part of the Institute for Promotion of Inter-University Collaboration (tentative name).
For collaborative projects based on bilateral and multilateral agreements, we focus on research plans within a limited budget and aim for higher results.
With respect to international projects such as the International Thermonuclear Experimental Reactor (ITER), NIFS plays a role of COE to further collaborate with universities under cooperation agreements in areas where NIFS has specialties.
In order to sustain the function of NIFS as the Inter-University Research Institute at a high level, the joint use rate of LHD and Plasma Simulator are maintained at 100%.

Third Midterm Plans of NSRP

- Effectively use Plasma Simulator for construction of the Numerical Simulation Reactor to advance the researches for the development, the extension, the high precision, and the integration of the 3D simulation codes
  - Model turbulent transport in core plasma and apply the model into the integrated transport code by the end of FY2019
  - Incorporate multiple ion species effects into various transport codes
  - Develop molecular dynamics simulation techniques and build new models necessary for evaluating physical properties of plasma facing materials such as tungsten
  - Improve the code accuracy by comparison with the experimental results on the three-dimensional equilibrium, transport, instability and nonlinear evolution of magnetically confined plasmas including LHD plasmas
- Conduct simulation researches on related basic physics
- Promote domestic and international collaborations including ITER
- Improve the performance of the Plasma Simulator more than four times compared to the current system during FY2019
  - Maintain the joint use rate Plasma Simulator at 100%.

Three-step plan of the NSRP:

1. To develop simulation codes for various physics elements of fusion plasmas
2. To integrate and validate simulation codes for treating multi-scale and multi-physics phenomena
3. To construct a system of codes [=Numerical Simulation Reactor (NSR)] for contributing to designing high-performance helical fusion reactor

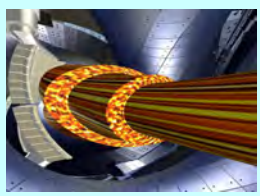
Roadmap for realizing Numerical Simulation Reactor (NSR)

2nd mid-term | 3rd mid-term | 4th mid-term

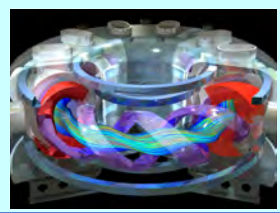
2010 — 2016 — 2019 — 2022 — 2028

Development of simulation codes for various physics elements constituting fusion plasmas

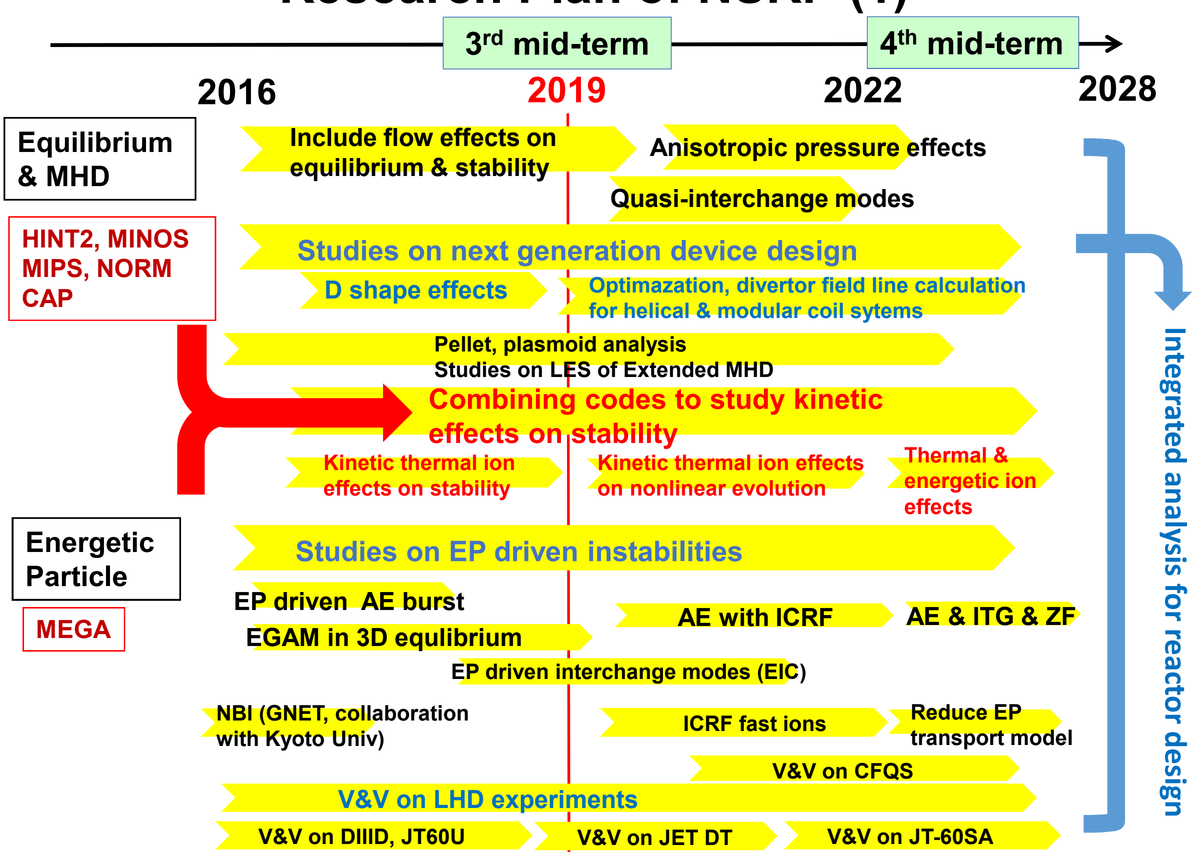
Extension and integration of codes for treating multi-scale and multi-physics phenomena V&V and application of codes by collaboration with experiments and engineering



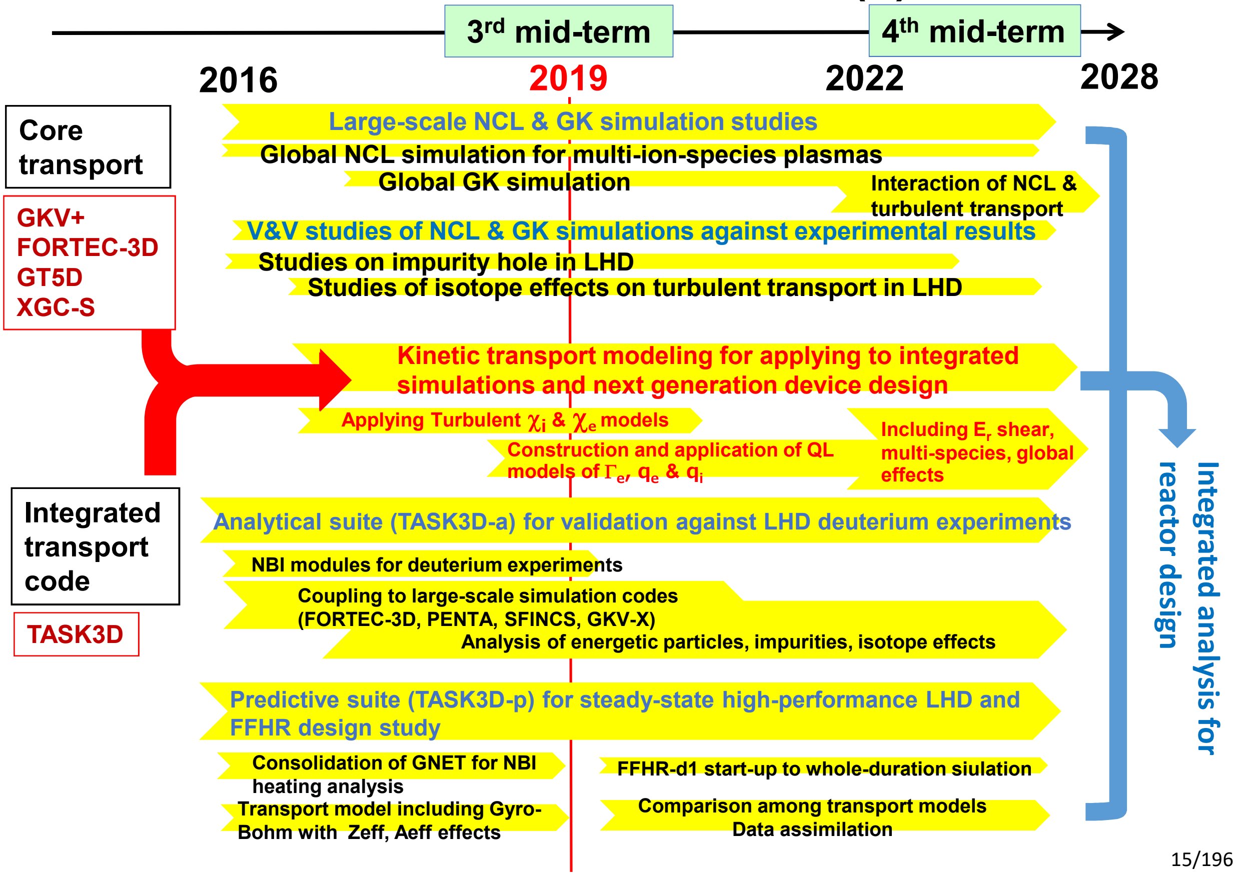
Further development and completion of NSR for contributing to designing high-performance helical fusion reactor



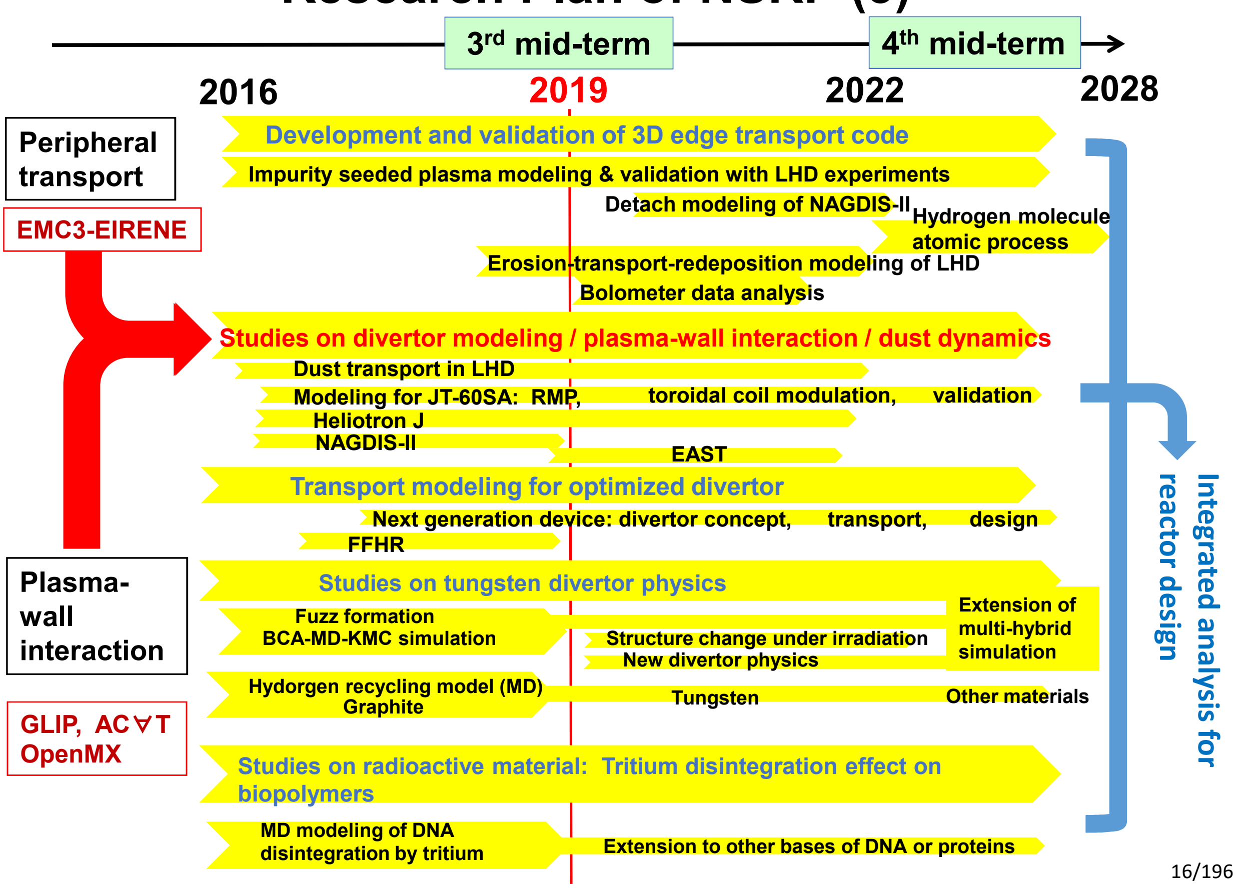
Research Plan of NSRP (1)



Research Plan of NSRP (2)



Research Plan of NSRP (3)



[1]-(2)

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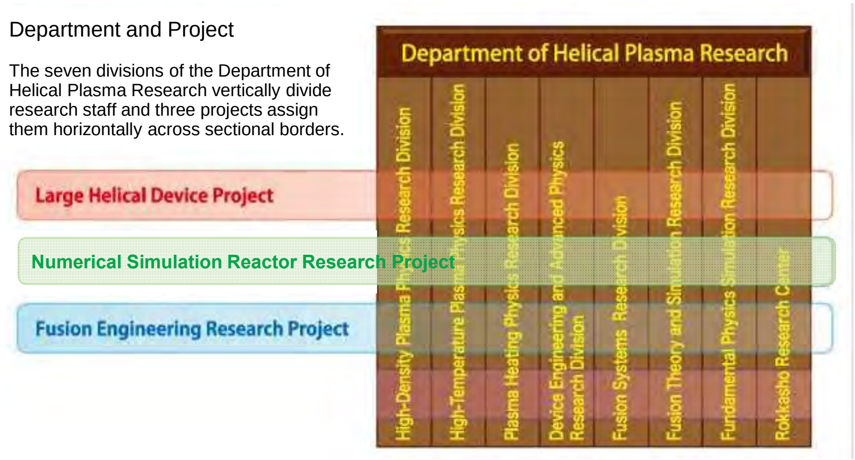
The NSRP performs its research activities in synergy with other projects under the framework of the NIFS research system

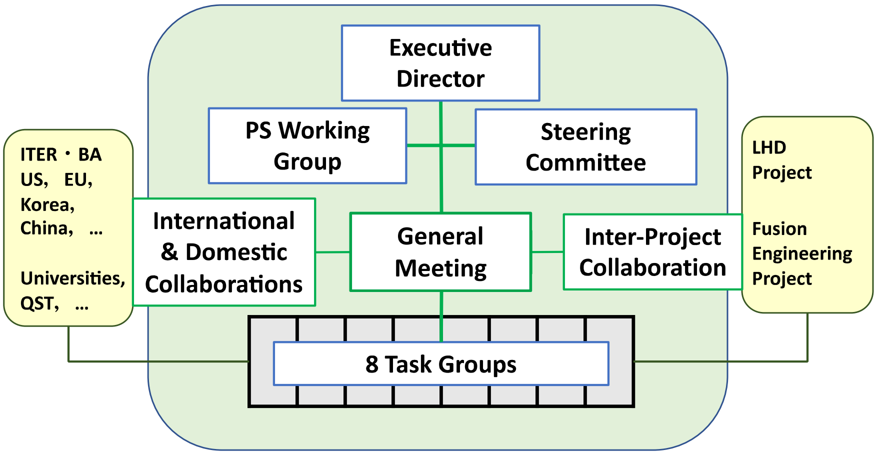
- [Research system] Research divisions are the warp of the research while the projects are the weft. Both are woven together to achieve the goal.



1. Development of research plan, system, and environment

(2) Does the research system function appropriately in accomplishing the objectives of the NSRP with attention to the management of step-by-step progress, research collaboration, and integration?

The research system of the NSRP is organized as shown below to enable flexible management of step-by-step progress, research collaboration, and integration of activities of 8 NSRP task groups, other NIFS Projects, and collaborators from outside of NIFS.



The eight task groups are organized to cover a wide range of fusion simulation subjects

group	leader	member
Plasma fluid equilibrium stability	K. Ichiguchi	13（sim. 7, exp. 3, collab. 3）
Energetic-particle physics	Y. Todo	9（sim. 4, exp. 3, collab. 2）
Integrated transport simulation	M. Yokoyama	28（sim. 4, exp. 13, collab. 11）
Neoclassical and turbulent transport simulaton	R. Kanno	16（sim. 8, exp. 3, collab. 5）
Peripheral plasma transport	Y. Suzuki	20（sim. 4, exp. 5, collab. 11）
Plasma-wall interaction	H. Nakamura	18（sim. 4, exp. 3, collab. 11）
Multi-hierarchy physics	H. Miura	18（sim. 12, collab. 6）
Simulation science basis	H. Ohtani	16（sim. 12, exp. 1, collab. 3）

Sim.: simulation staff, exp.:experiment staff, collab.:domestic collaborators

- Many collaborators from other projects and from outside NIFS have joined these task groups to enhance collaboration and cooperation studies.
- Most of the simulation staff in the NSRP also participate in other task groups.

Steering Committee consists of the **executive director**, two division directors, and task group leaders.

The meeting is periodically (once a month) held to manage the NSRP activities to function appropriately as a whole.

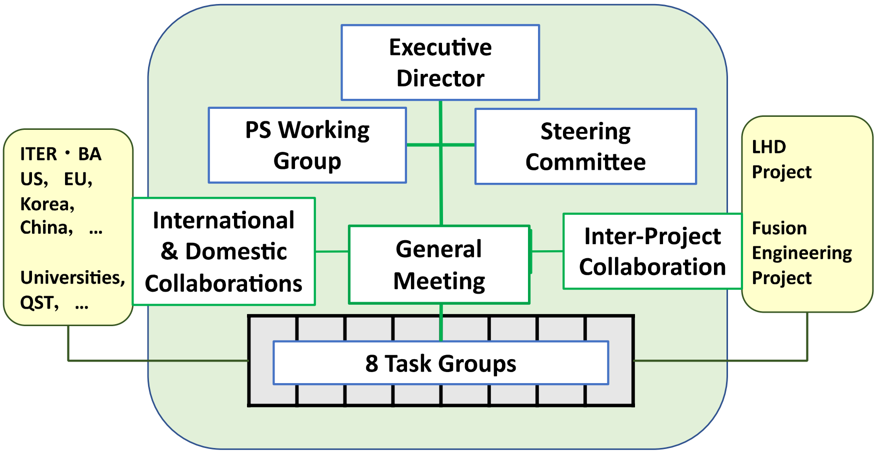
Step-by-step progresses are checked and saved in a File of Milestones.

General Meeting is held once a month, and is chaired by group leaders in rotation, enhances fast and smooth communication among all NSRP members.

Joint research activities , progresses, and information related to NSRP and PS are discussed.

Publishments of research results and presentations in international conferences are checked.

Plasma Simulator (PS) Working Group consists of a Leader and five members, manages and operates PS and LHD Numerical Analysis Server in collaboration with Fujitsu system engineers.



Progress of NSRP, Inter-Project collaboration, and joint researches based on Plasma simulator are checked with domestic collaborators

- Meetings to report results of NSRP
  - Meeting to report results of all three Projects (in June): Progress of three Projects made in the past year are checked with domestic collaborators.
  - Plasma Simulator Symposium (in September): Results from PS joint researches are checked and PS operation management is discussed.
- Inter-Project collaboration
  - Validation of simulation results is done in comparison with results from LHD experiments in collaboration with the LHD Project.
  - Predictions of performance of FFHR are made in collaboration with the Fusion Engineering Project.
  - Contributions to optimization and design studies of high performance helical devices are made. (→ Chap.6)

[1]-(3)

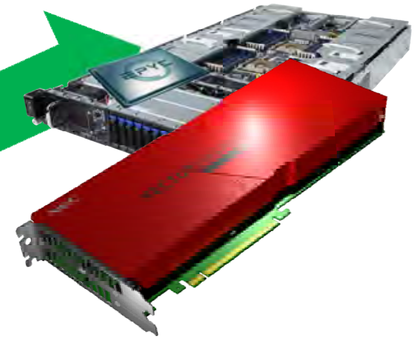
1. Development of research plan, system, and environment

(3) Is the environment of the “Plasma Simulator” system and its related research appropriately developed and effectively utilized accordingly to the research plan? Is the installation of a higher performance supercomputer properly planned?

(1) The computer system Working Group manages and operates the Plasma Simulator and LHD Numerical Analysis Server in collaboration with Fujitsu system engineers (since June 1, 2015) to make the research environment function appropriately.
(2) More than 50 projects each year are performed as Plasma Simulator Collaboration Research.
(3) The research for upgrading Plasma Simulator has been properly conducted and the installation of a higher performance supercomputer is to be completed by June 2020 (one year behind the schedule in the midterm plan).
(4) Virtual-reality (VR) system “CompleXcope” was upgraded.

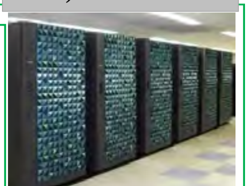
"Plasma Simulator" is going to be upgraded to a new system: total peak performance more than 10 Petaflops in June 2020

- **Plasma Simulator** is going to be replaced to a new system in June 2020.
- The peak performance of the new PS system is more than four times of the current FX100 system (to be operated until the end of Feb. 2020.)



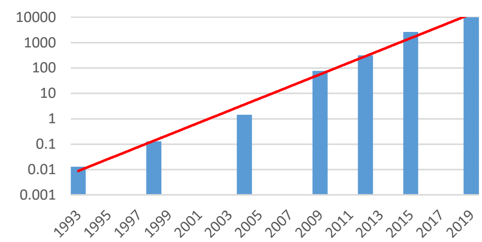
HITACHI SR16000/L2 (peak speed:**77TF** memory: **16TB** period: 2009 – 2012)

HITACHI SR16000/M2 (peak speed: **315TF** memory: **40TB** period: 2012 – 2015)



FUJITSU PRIMEHPC FX100 (peak speed: **~2.6PF** memory: **~81TB** period: 2015-2020)

NEC (model name TBD) (peak speed:**~10.5PF**, **memory:~200TB:** period:2020-2025)



The "Plasma Simulator" system has been developed and periodically upgraded for the NSRP

- Phase 1 (March 2009 – August 2012): HITACHI SR16000 model L2, with 128 nodes
- Phase 2 (October 2012 – March 2015): HITACHI SR16000 model M1, with 322 nodes
- June 2015 – Feb 2020: FUJITSU PRIMEHPC FX100 with 2592 nodes
- June 2020 – May 2025: NEC (model name TBD) with 4320 VE, VE = Vector Engine (accelerator), 2.433 Fflops, 48GiB memory for each VE.

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	Peak Performance	Memory	Storage
HITACHI SR16000 model L2 (Phase 1)	77 TFlops	16 TB	0.5 PB
HITACHI SR16000 model M2 (Phase 2)	315 TFlops	40 TB	2.0 PB
FUJITSU FX-100	2.62 PFlops	81 TB	10.0 PB
NEC (model name TBD)	10.5 PFlops	202TB (VE part)	32.1 PB

FUJITSU PRIMEHPC FX100 in NIFS

- Plasma Simulator was ranked for 65th in the world (7th in Japan) in June 2009, 96th (8th in Japan) in Dec. 2012, and 27th (3rd in Japan) in June 2015 on the "TOP 500 LIST".
- PS was ranked12th in the world (2nd in Japan) on the "High Performance Conjugate Gradients (HPCG)" in June 2015, too.

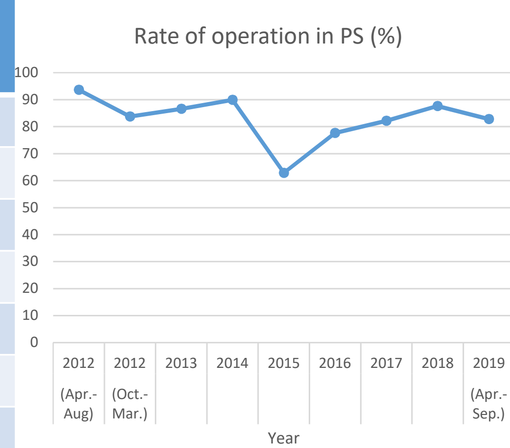
Virtual-reality (VR) system “CompleXcope” was upgraded and head-mount display (HMD) was set up.

- Since Plasma Simulator was upgraded, it was expected that the size of simulation data increased explosively. High-spec computer systems (Linux and PC cluster) and higher brightness projectors were installed for analysis of such large-scale simulation data in VR space.
- A head-mount display was also set up for another visualization method.
- A game development engine “Unity” was installed as a common development environment.

- It is expected that larger size simulation results can be analyzed in VR space.
- We can build easier VR develop environment by using Unity to make VR visualization software for CAVE, HMD, and so on.

More than 50 projects every year were performed as Plasma Simulator Collaboration Research

FY	Collab. Research Projects	Users (NIFS/Univ.)	Simulation Jobs
2012	56	169 (50/119)	16,684
2013	51	158 (50/108)	19,548
2014	53	162 (50/112)	21,540
2015	60	154 (49/105)	46,078
2016	65	184 (50/134)	70,041
2017	67	194 (45/149)	90,730
2018	68	194 (50/144)	96,796
2019	68	183 (54/129)	31,407 (Apr.-Sep.)



- There are about 160-190 users each year with 60 or less from NIFS and 105-149 or more from universities.
- More than 90,000 jobs are run on Plasma Simulator in recent years.
- The average operating rate (ratio of successful computations to the total machine time) is 80-90%.

The computer system Working Group manages and operates Plasma Simulator and LHD Numerical Analysis Server in collaboration with FUJITSU system engineers

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- Tasks
    - user registration, computer resources allocation, operation scheduling
    - management of hardware and software troubles
    - web site (figure): user manual, Q&A, text of user course, etc.
- Operation meeting is held every month to grasp and resolve issues.

Research assistance system has been developed for collaboration studies in the NSRP

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- **User course** is held at the beginning of each fiscal year regarding
    - how to use the Plasma Simulator and the LHD Numerical Analysis Server
    - program tuning (code optimization)
    - OpenMP and MPI (parallel computing)
    - AVS/Express (scientific visualization)
- Three system engineers from Fujitsu corporation are permanently working in the **Program Development Support Office** in NIFS
    - one engineer for operation support
    - two engineers for users' program development support
- In response to users' requests and questions, program development support engineers assist users in:
    - optimizing programs on FX100
    - parallelizing programs with SMP (auto parallelization), OpenMP and MPI
    - finding unexpected/invisible troubles in simulation codes
- **158 cases,** including 28 cases from universities, have been assisted for **program development support** since March 2009.

[2]-(1)

2. Research achievements

Does the NSRP produce high-level achievements in accordance with international standards for the following research areas described in the third midterm goal and plan by promoting theory and computer simulation research utilizing the Plasma Simulator?

(1) Construction of the Numerical Simulation Reactor, Validation and improvement of simulation codes through comparison to experimental results

Presentation by Y. Todo

(2) Academic systematization of fusion science and related science and engineering

Presentation by S. Ishiguro

(3) Are research achievements steadily made according to the plan of the NSRP?

Presentation by H. Sugama (2)

2. Research achievements

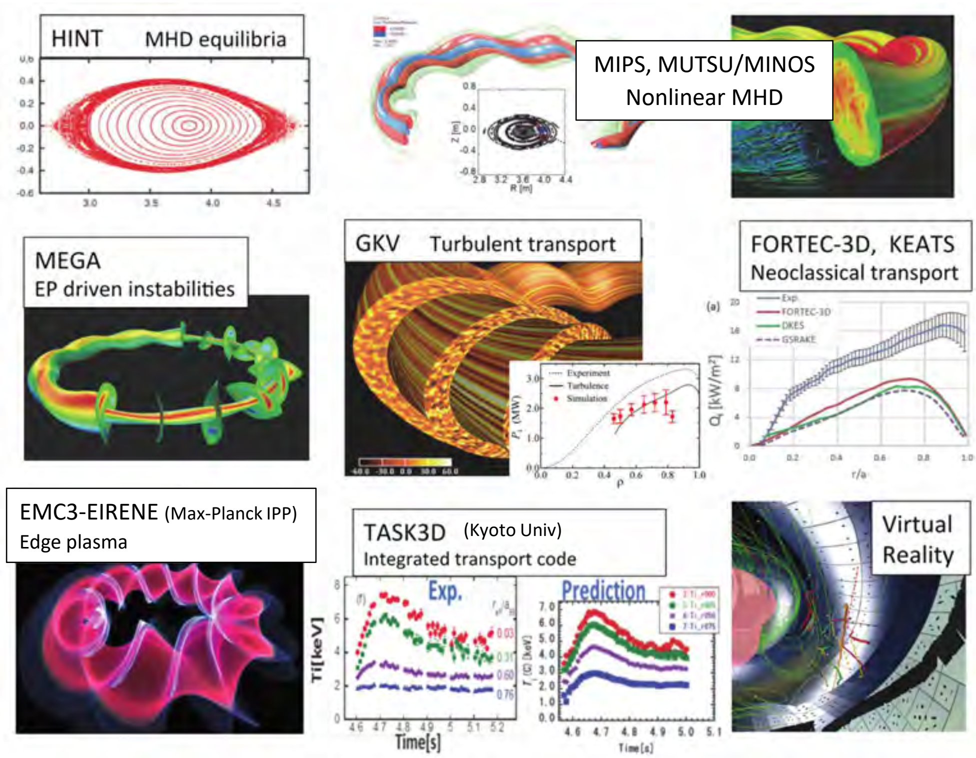
Does the NSRP produce high-level achievements in accordance with international standards for the following research areas described in the third midterm goal and plan by promoting theory and computer simulation research utilizing the Plasma Simulator?

(1) Construction of the Numerical Simulation Reactor, Validation and improvement of simulation codes through comparison to experimental results

The NSRP produces a large number of high-level achievements in theory and simulation research for construction of the Numerical Simulation Reactor.

- Development, coupling, and integration of various simulation codes, which constitute the Numerical Simulation Reactor, have progressed.
- Validations of codes by comparisons with experiments in LHD and other devices have progressed.
- These simulation codes contribute to numerous analyses of fusion plasmas in LHD and other devices as well as to predictions of FFHR plasma performance (and optimization of magnetic configuration → Chap.6).

Extensive simulation code developments and comparisons between simulation and experiments have been performed



Simulation researches toward construction of the Numerical Simulation Reactor

- Integration of MHD and energetic particle simulations
- Neoclassical and turbulent transport

  Modeling of turbulent transport for integrated code simulation
- Integration of peripheral transport and PWI simulation
- Integrated code

  Application to analysis and prediction of experiments

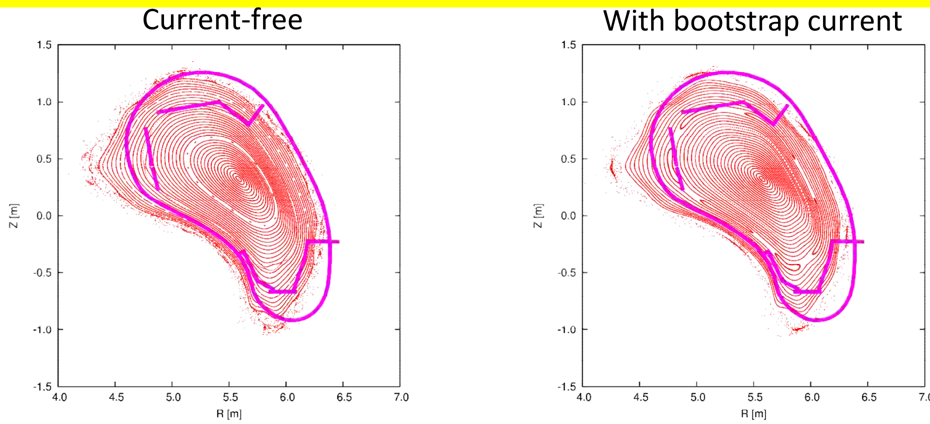
  Contributions to fusion reactor design

Integration of MHD and energetic particle simulations, and the validation for construction of the Numerical Simulation Reactor

- 3D MHD equilibrium, effects of plasma flow on interchange modes, nonlinear evolution of ballooning modes, and pellet injection with magnetic islands for LHD plasmas
- Extension of the EP-MHD hybrid code MEGA towards the integration of MHD and EP simulations
- Energetic particle driven geodesic acoustic mode and energy channeling to thermal ions
- Comprehensive simulations of energetic-particle (EP) driven instabilities with beam injection and collisions
- Full PIC simulation of high-frequency energetic-ion driven instabilities and time-dependent plasma heating analysis

Impacts of plasma beta and toroidal current density are studied by 3D equilibrium calculation code HINT

- For current-free case, 5/6 islands vanish (self-healing), 10/12 islands become visible.
- But, for bootstrap current included, islands at boundary appears, but those are smaller than vacuum islands.



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- To control divertor islands, active control, which are planar coils, sweep coils, will be necessary.

3D flow mapping from 1D experimental data

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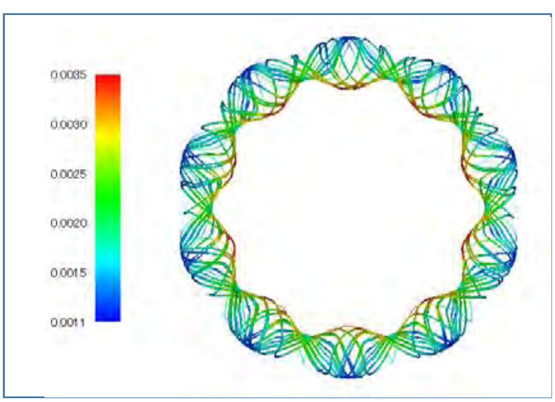
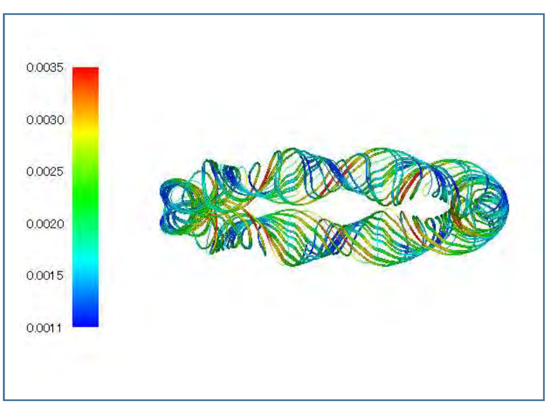
- FLOWVM code is developed.
- The global flow is calculated with the the VMEC equilibrium and 1D experimental data.

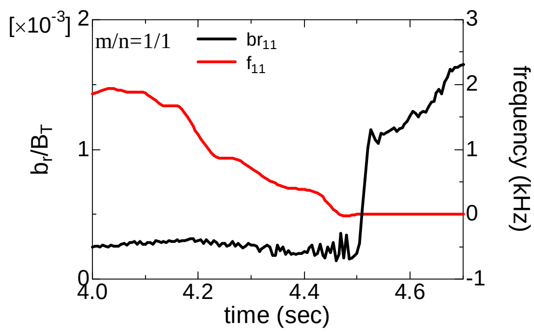


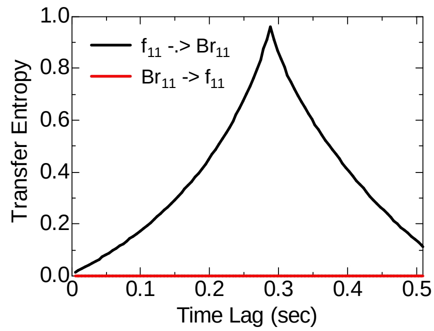


- The flow data in the whole plasma region can be obtained.
- This code gives a mapping of the 1D data to the 3D region.

Causality between the fluctuation excitation and the mode rotation stopping is analyzed with transfer entropy.

- Causality can be analyzed by means of the transfer entropy.
- This technique is applied to the magnetic fluctuation excitement and the mode rotation stopping in the collapse observed in the LHD experiments.





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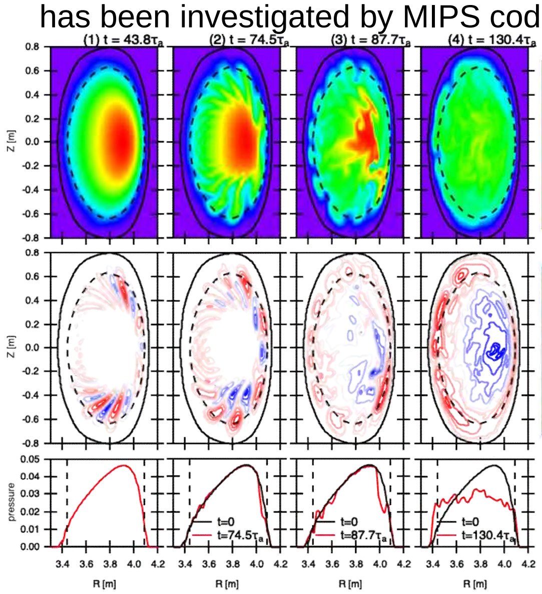
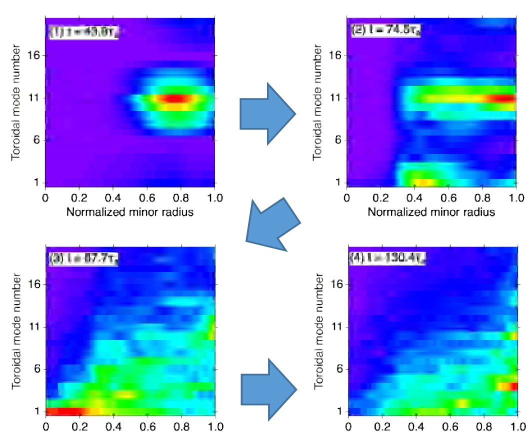
- It is obtained that the information is transferred from the rotation frequency to the magnetic fluctuation and the information is not transferred in the opposite direction.
- This result suggests that the rotation stopping caused the fluctuation excitement.

The ballooning modes destabilized in the peripheral region can lead the core crush.

[M. Sato, N. Nakajima, K. Watanabe, Y. Todo, Nucl. Fusion (2017)]

- The nonlinear evolution of resistive ballooning modes in high beta LHD plasmas has been investigated by MIPS code.



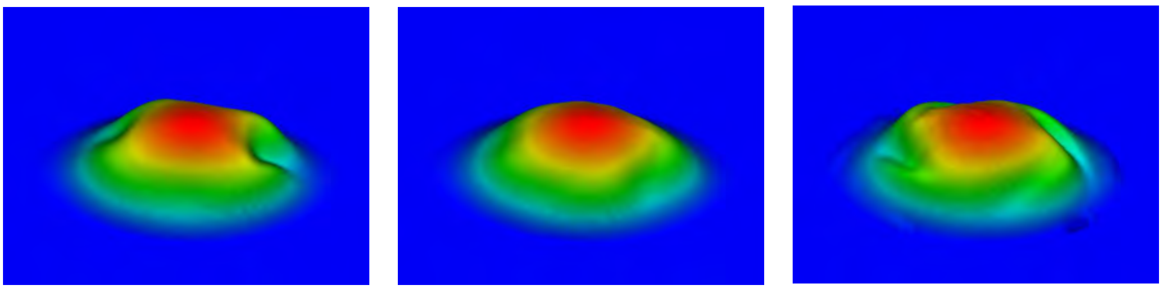


Time evolution of the radial spectral distribution of the perturbed pressure.

- Low toroidal modes typified by the n=1 mode are nonlinearly generated by resistive ballooning modes with n∼10 destabilized in the peripheral region.
- The self mode coupling of the low *n* modes induces the core crush.

Stabilizing window appears in background shear flow.

- The calculation scheme of 3D background flow consistent with 1D experimental data is established.
- Nonlinear interaction between the interchange modes and the background global flow is numerically studied in LHD plasmas with the MIPS code.



- The effects of the global flow on the interchange modes are analyzed by increasing the flow velocity amplitude.
- The flow stabilizes the interchanged mode up to 10 times larger than the observed value, however, the flow destabilizes the Kelvin-Helmholz mode beyond 30 times larger than the observed value.

MHD simulations of the pellet injection in LHD plasmas with and without islands have been performed

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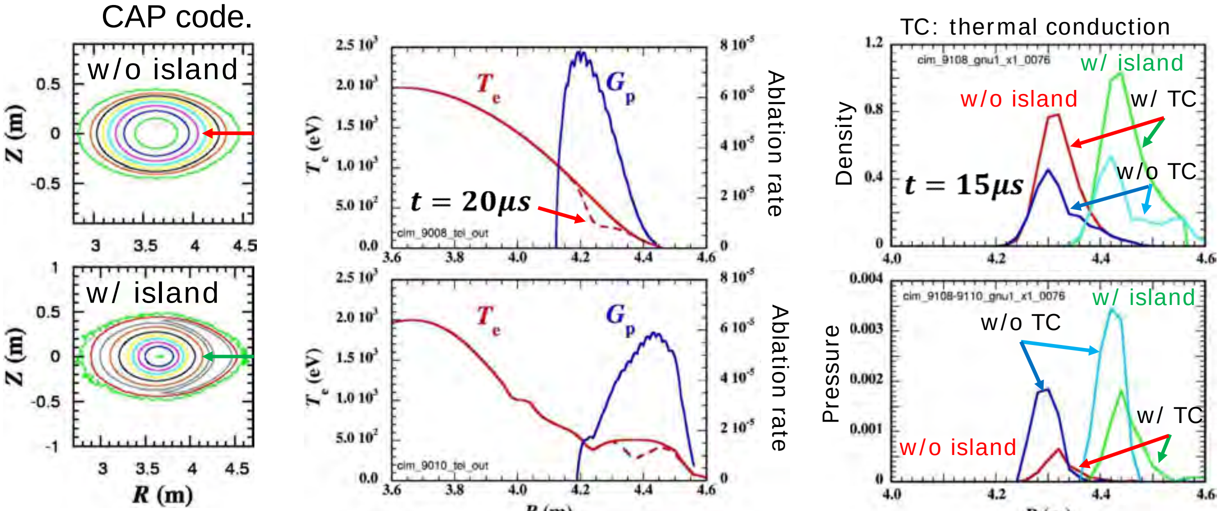
- MHD simulations including the ablation processes have been performed
CAP code.



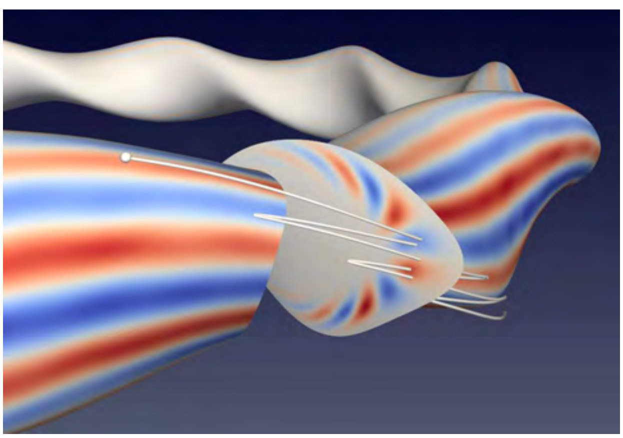
- The ablation rates are different between in LHD plasmas with and without islands due to the difference of the electron temperature. The density peak is located in the vicinity of the o-point in the plasma with the island.
- The ablation pressure increases because no diffusion occurs in the case without the thermal conduction. In result, since the pressure gradient increases, the density decreases due to the elongation of the plamoid along the field line.

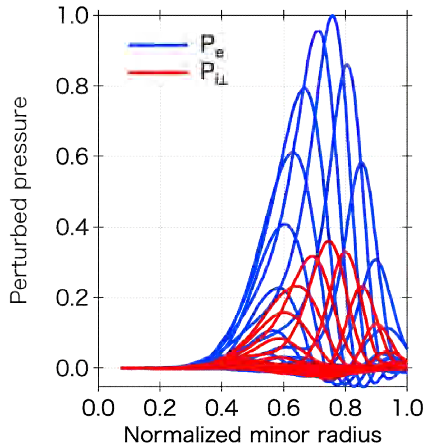
Integration of MHD and Energetic Particle Simulations

Precession drift motion of trapped thermal ions suppress the ballooning modes in LHD plasmas.

[M. Sato and Y. Todo, Nucl. Fusion (2019)]

- Effect of the thermal ions on the resistive ballooning modes in the LHD plasmas has been investigated by MEGA code based on the kinetic MHD model.





- The response of the trapped ions to the MHD instability is weakened by the poloidal precession drift motion of the trapped ions.
- This results in the suppression of the ion perpendicular pressure perturbation to the magnetic field leading to the reduction of the linear growth rate.

The kinetic-MHD hybrid code MEGA was extended to simulate kinetic thermal and fast ions

- The PIC simulation is applied to both thermal and fast ions.
- The time evolution of an Alfvén eigenmode was compared between bulk plasma beta 1% and 4%.

Invited talk at EPS (2019)

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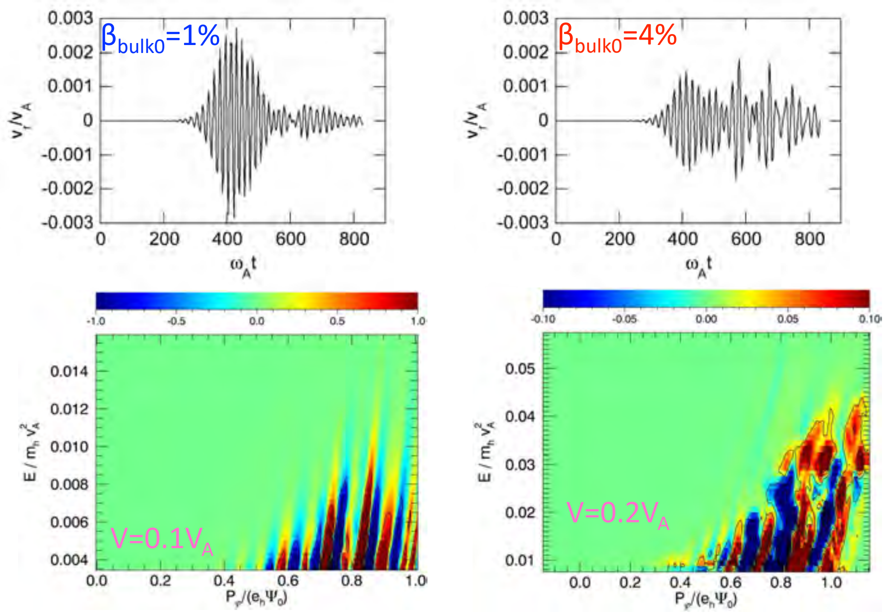
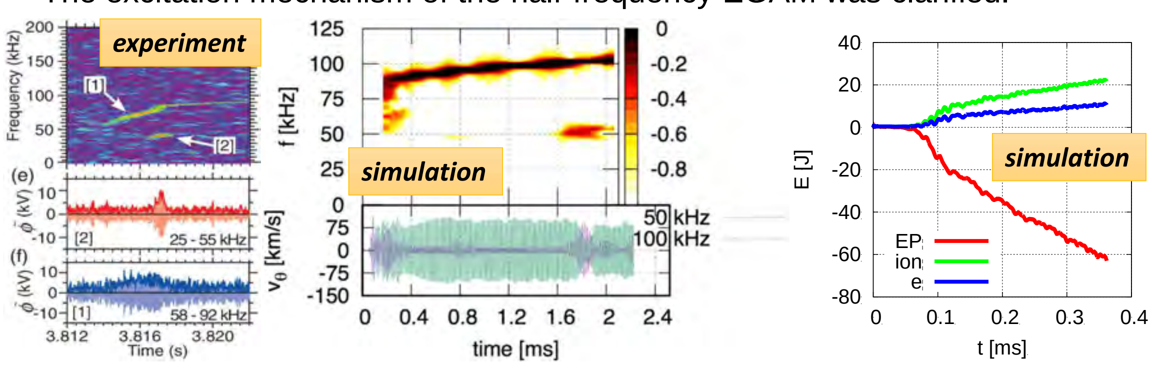


- It was demonstrated that the saturation level of a toroidal Alfvén eigenmode is reduced for higher bulk temperature.
- The reduction of saturation level can be attributed to thermal ion Landau damping.

Nonlinear evolution of EP driven geodesic acoustic mode and energy channeling were clarified

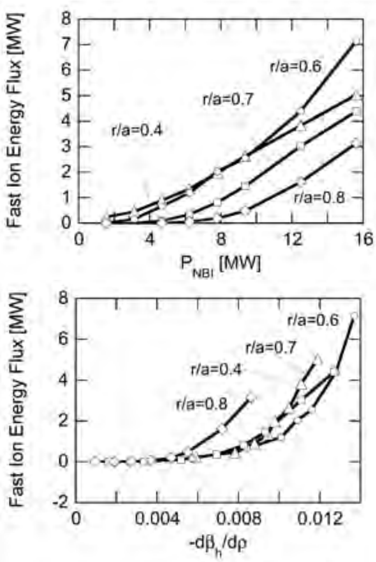
- Chirping energetic-particle driven geodesic acoustic mode (EGAM) and the sudden excitation of a half-frequency EGAM were reproduced with the MEGA code for a 3D LHD equilibrium. [Wang+(PRL2018)]
- The simulated results including mode numbers, frequencies, profiles, and phase relations, are in very good agreement with experimental measurements.
- The excitation mechanism of the half-frequency EGAM was clarified.

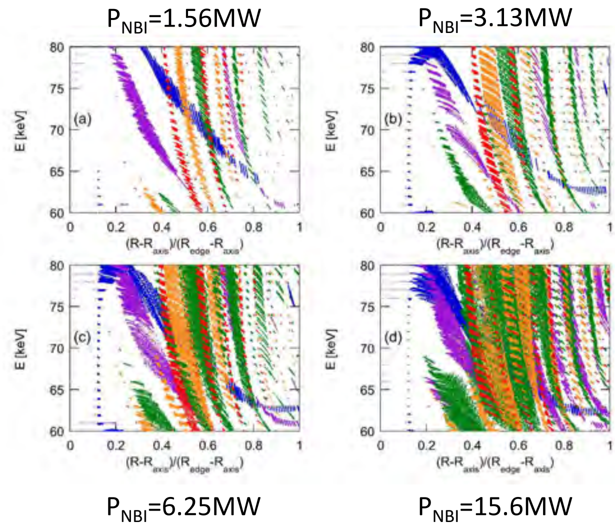


- The bulk ions are kinetically modeled, and the EGAM channeling in LHD was successfully simulated. [Wang+(NF2019)]
- The sideband resonance plays an important role in bulk ion heating.

Fast-ion profile stiffness with increasing beam power

- Sudden increase in Alfvén-eigenmode-induced fast-ion transport with increasing beam power observed in DIII-D experiments is reproduced by comprehensive kinetic-MHD hybrid simulations.
- Resonance overlap of multiple eigenmodes accounts for the sudden increase in fast ion transport with increasing beam power.

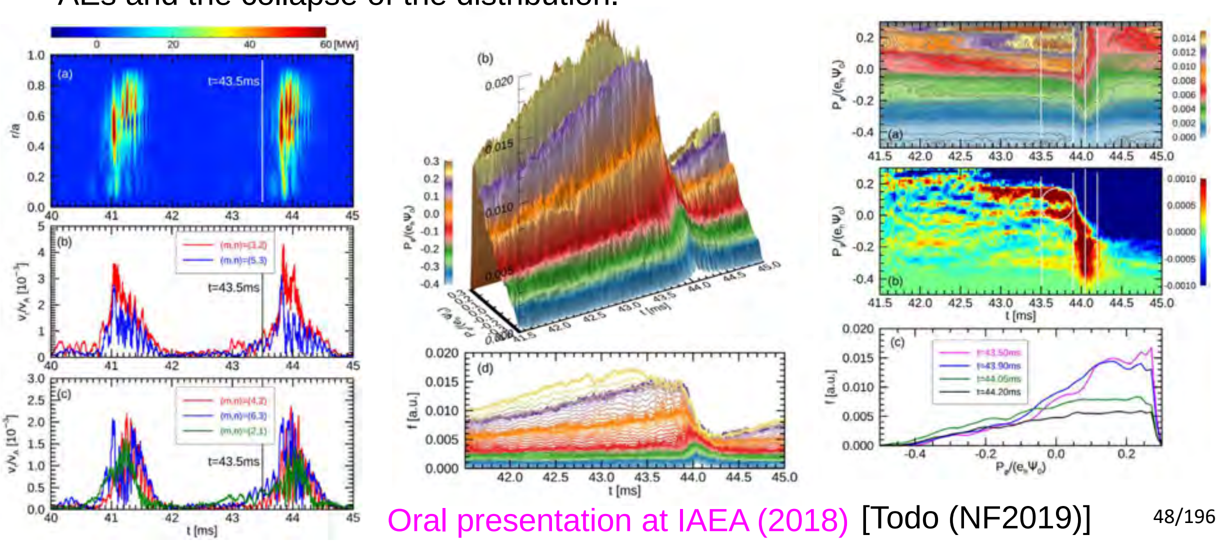




[Todo+(NF2016)] NF Highlights of 2016

Critical energetic particle distribution in phase space for the Alfvén eigenmode burst with global resonance overlap

- Comprehensive computer simulations of the Alfvén eigenmode (AE) bursts.
- Energetic-particle distribution in phase space reaches a ‘critical distribution’ with a stairway structure just before the AE burst.
- When the distribution reaches the ‘critical distribution,’ a resonance overlap triggers multiple resonance overlaps leading to the synchronized growth of AEs and the collapse of the distribution.



Oral presentation at IAEA (2018) [Todo (NF2019)]

Alfvén eigenmode bursts in LHD experiments were simulated with the kinetic-MHD hybrid code

- Alfvén eigenmode bursts in the LHD experiment #47645 were simulated with the realistic NBI deposition profile and collisions of fast ions with the bulk plasma.
- The Alfvén eigenmodes (AEs) and the alternate growth of the two AEs in the simulation were consistent with the experiment.

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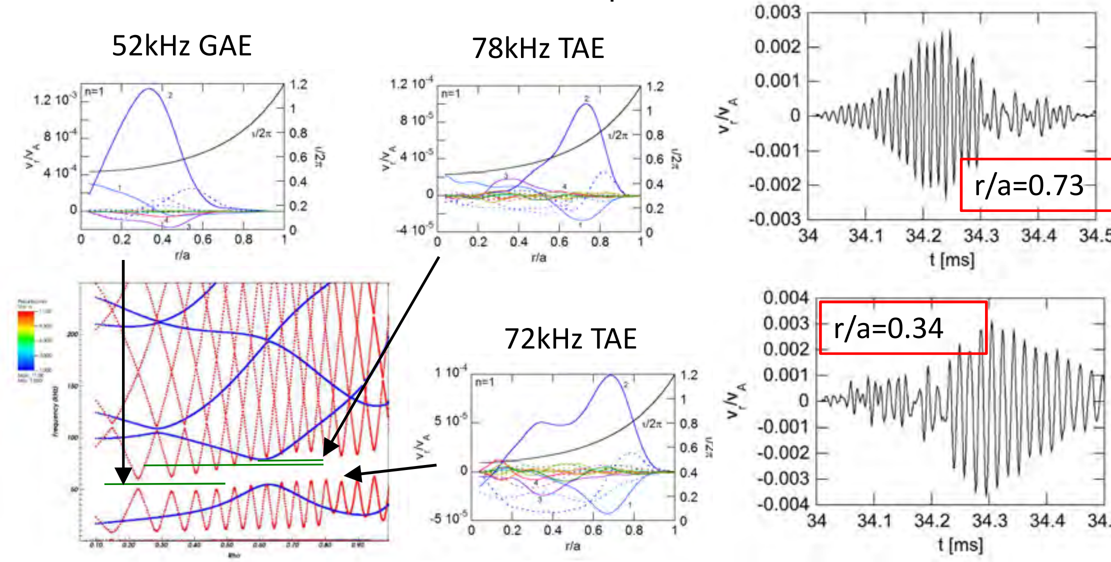
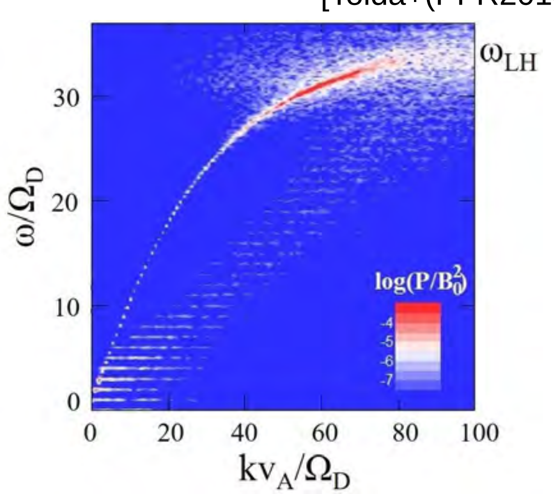


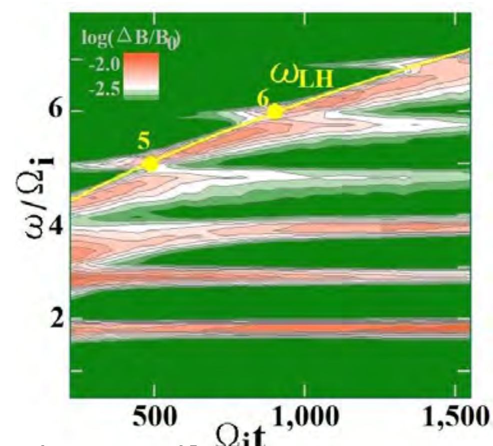
shear Alfvén continuous spectra [Todo+(PoP2017), Seki+(NF2019)]

Full PIC simulations of energetic-ion driven instabilities near lower hybrid resonance frequency have been performed

- PIC simulation with full ion and electron dynamics have shown that energetic ions with a ring-like velocity distribution excite waves with frequencies near the lower-hybrid resonance frequency ω_{LH}, in addition to ion cyclotron wave and its harmonics.

[Toida+(PFR2018)]





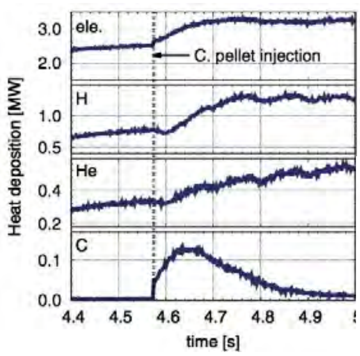
[Toida+(PFR2019)]

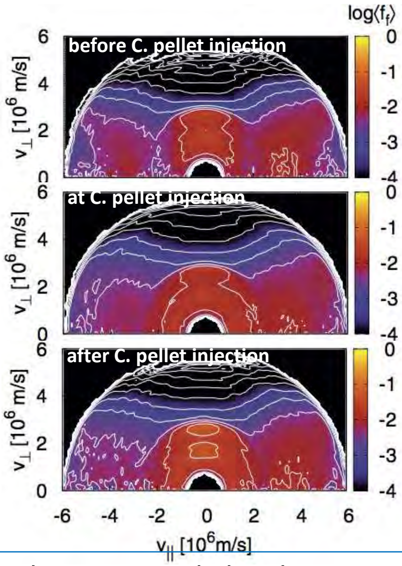
- Instabilities driven by energetic ions injected continuously in a plasma with increasing density and ω_{LH} are studied. It has been shown that the stair-like frequency chirping with the riser Ω_i appears near ω_{LH}.
- The simulation results agree with the LHD experimental results.

NBI heating analysis of LHD deuterium experiments

NBI analysis of time-dependent, multi-ion-species plasma

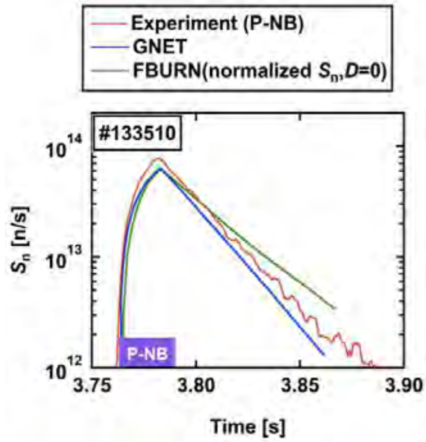
[Yamaguchi+(NF2016)]





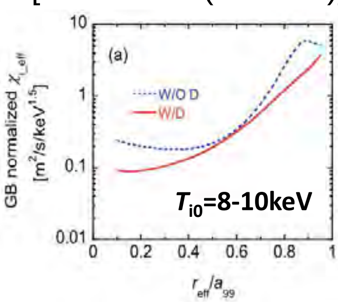
Evaluation of neutron emission rate in NB-blip experiment

[Ogawa+(NF2019)]



Power-balance analysis of H/D plasma of LHD

[Takahashi+(NF2018)]



- The GNET code has been extended for time-dependent, multi-ion-species plasma and contributed to isotope effect study.
- Confinement of fast ions by P-NB was found to be neoclassical by comparing neutron emission rate by GNET and blip-experiment.
- Benchmark of CONV_FIT3D and TASK/FP using experimental data and GNET is in progress (➔TASK3D-a).

Summary of research achievements in Integration of MHD and energetic particle simulations, and the validation

- 3D MHD equilibrium, effects of plasma flow on interchange modes, nonlinear evolution of ballooning modes, and pellet injection with magnetic islands were studied for LHD plasmas.
- The EP-MHD hybrid code MEGA was extended to simulate kinetic thermal ions towards the integration of MHD and EP simulations.
- The extended MEGA simulations with kinetic thermal ions demonstrated that precession drift motion of trapped thermal ions suppress the ballooning modes in LHD plasmas.
- Nonlinear evolution of energetic particle driven geodesic acoustic mode and energy channeling to thermal ions were well reproduced.
- Comprehensive simulations of energetic-particle (EP) driven instabilities with beam injection and collisions revealed that resonance overlap of multiple Alfvén eigenmodes (AEs) accounts for the critical beam power for the sudden increase in fast-ion transport and the trigger of AE burst.
- Full PIC simulation of high-frequency energetic-ion driven instabilities and time-dependent plasma heating analysis have been developed.

Neoclassical and Turbulent Transport Simulations

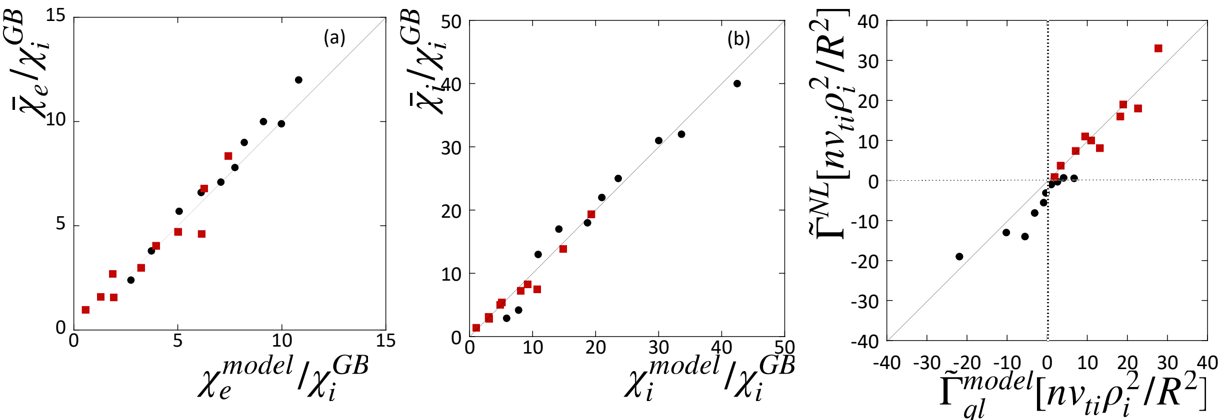
Neoclassical and Turbulent Transport Simulations for construction of Numerical Simulation Reactor

- Reduced models of turbulent transport based on Gyro-Kinetic (GK) simulations for the integrated transport simulation code TASK3D
- A new global transport code TRESS+GKV for simulating time evolution of tokamak core plasmas.
- Investigation of isotope effect on the confinement of LHD plasmas by the gyro-kinetic simulation code GKV
- V&V Studies on mechanism of impurity hole formation in LHD plasmas by using both gyro- and drift-kinetic transport simulation codes, GKV and FORTEC-3D
- Extension of the global full-f gyro-kinetic simulation code GT5D for investigating turbulent and neoclassical transport in helical plasmas

Construction of reduced models for turbulent transport

S. Toda, Invited talk: AAPPS-DPP B-I46 (2018)
S. Toda et al., Phys. Plasmas **26**, 012510 (2019)
Most Read, download top15, 12/15

- The reduced models for the heat diffusivities and the quasilinear flux model for the particle transport based on the GK simulation for the kinetic electron condition are obtained for the transport simulation.
- For the representative plasmas where Ion Temperature Gradient (ITG) mode is unstable, the plasmas at t=1.8s, t=1.9s, and t=2.2s for LHD#88343 are chosen.

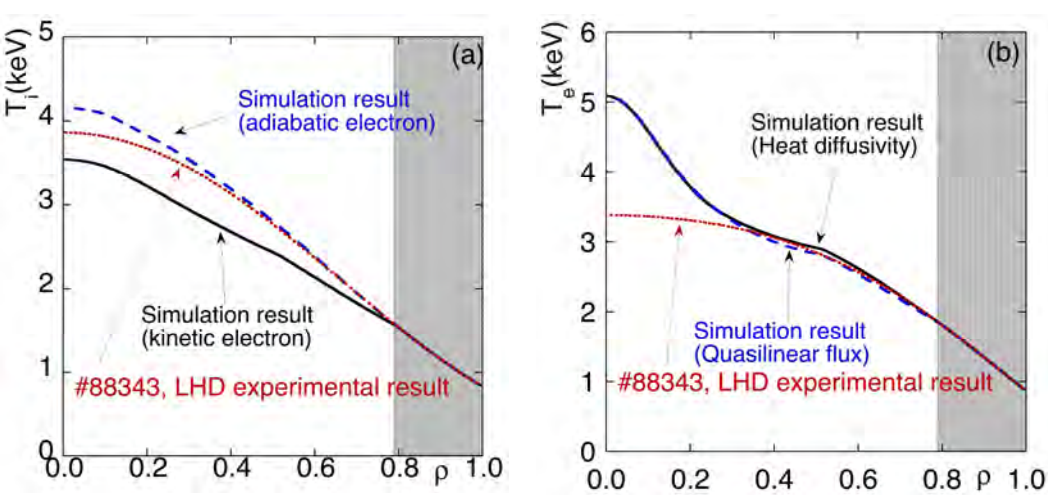


■: t=1.8s、1.9s, R_{ax}=3.6m (#88343 LHD)
●: t=2.2s, R_{ax}=3.75m (#88343 LHD)

Transport simulation by use of gyrokinetic transport model

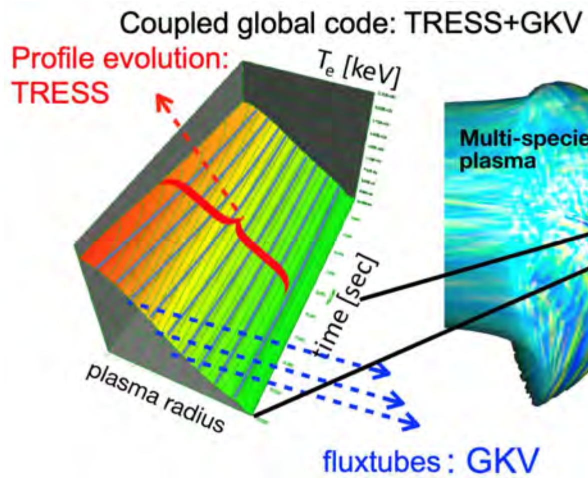
S. Toda et al., Plasma and Fusion Research **14**, 340306 (2019)

- Transport analysis by the integrated code, TASK3D, by use of heat diffusivity models based on the GK simulation results for the kinetic electron condition

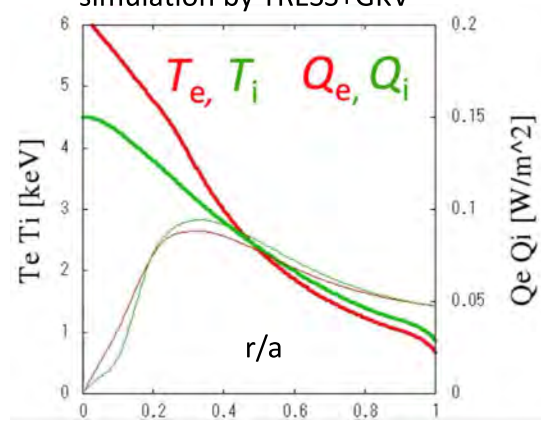


Co-Development(NIFS-QST) of a new coupled global gyrokinetic transport code: TRESS+GKV

- Based on collaborations with QST, a new global transport code TRESS+GKV is developed, and the both (multiple) ions and electron transport simulation framework is established.
- TRESS+GKV is for tokamak application at the moment, but is being extended to 3D system including the direct coupling with the MHD equilibrium solver.



Ion & electron global simulation by TRESS+GKV

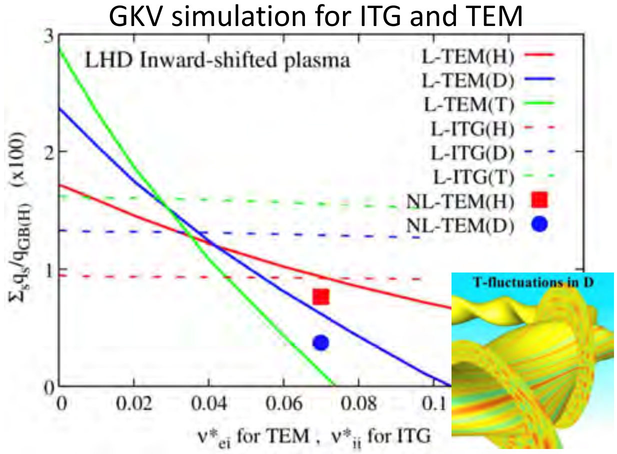


Nakata IAEA-TM2017(invited), APTWG2017, Plasma2017
Honda JSPS2018, CPC2018

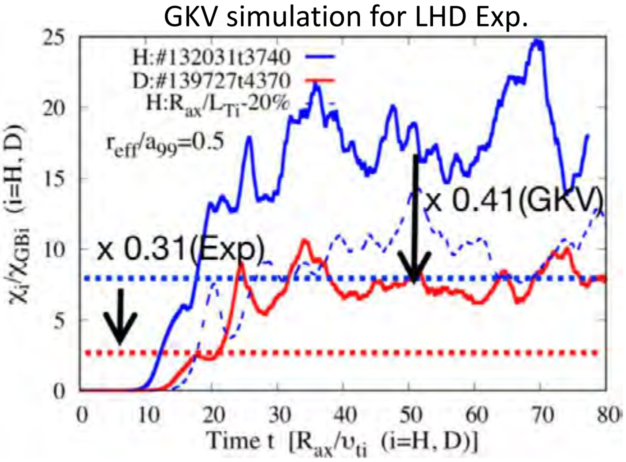
Isotope effects on turbulent transport and zonal flows: Cooperative studies with GKV & LHD experiments

- Nonlinear GKV simulations for LHD isotope plasmas reveals a significant isotope mass impacts on turbulence and zonal flows.
- Experimental trend of improved confinement is reproduced for LHD D-plasmas.

GKV simulation for ITG and TEM



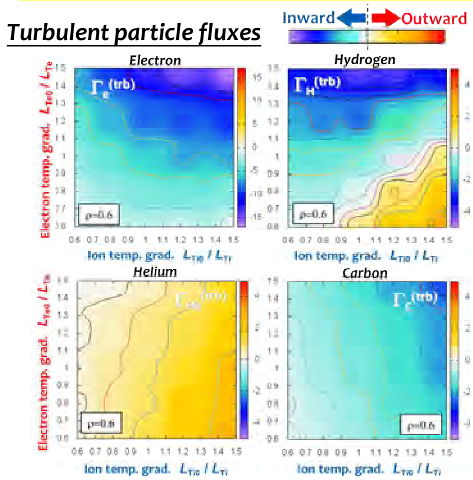
GKV simulation for LHD Exp.

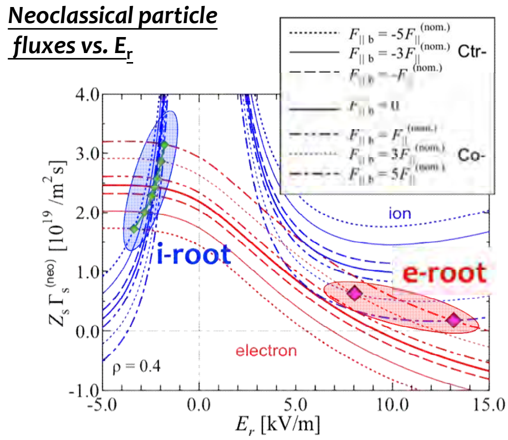


Nakata PPCF2016, PRL2017, PPCF2019
Nakata ISHW2017(invited), EPS2018 (invited),
K. Nagaoka FEC2018(oral) K. Tanaka EPS2019(invited)
Nakata JSPF research award(2017), NINS young researcher award(2018)

Gyrokinetic and drift-kinetic simulations for LHD impurity hole plasma

- Comprehensive analyses for anomalous and neoclassical transport of multi-ion-species plasmas in helical systems are performed by local gyrokinetic and drift-kinetic simulations.





- $\Gamma_C^{(trb)}$ remains inward directed within wide ranges of the gradients.
- $\Gamma_C^{(neo)}$ can be outward with electron-root E_r if there exists sufficient direct contributions of injected beam.

Plasma profile sensitivities in turbulent transport of helical plasmas

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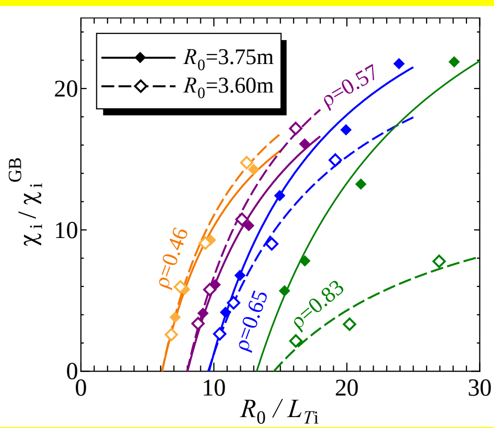
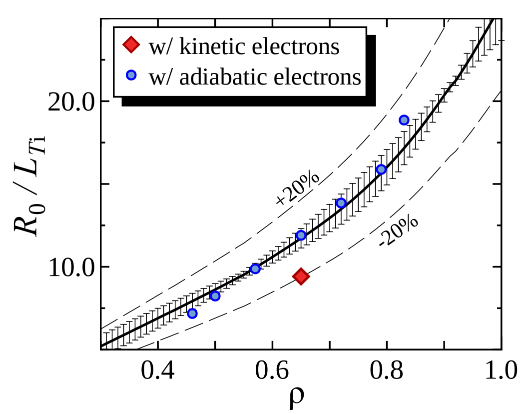
- Ion temperature gradient (ITG) turbulent transports are evaluated by gyrokinetic simulations using GKV code.
- For wide range of temperature gradients, the heat transport fluxes are estimated to perform flux-matching (FM) method.

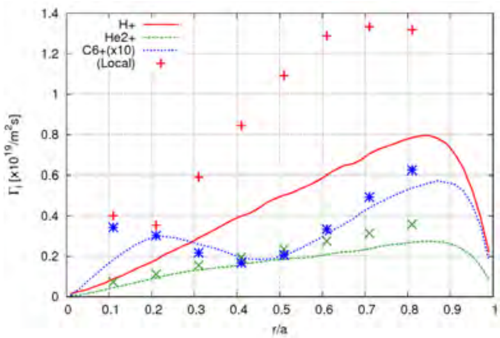




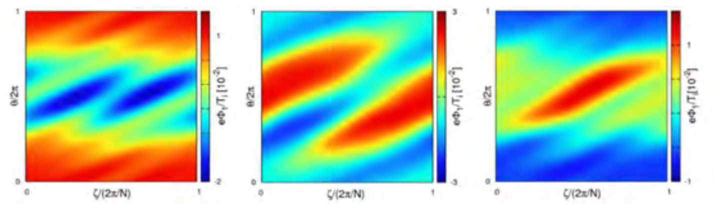
- In NC optimized case, the profile stiffness in turbulent transport is relaxed.
- Based on the profile sensitivities, we succeed to predict the temperature gradient by FM method against experimental error bars of the gradients which are obtained by AIC (Akaike's information criterion).

Global neoclassical transport simulation codes for multi-species plasma is being developed

- FORTEC-3D code, which solves the 5D drift kinetic equation by 2-weight δf scheme, treats the non-local neoclassical transport phenomenon including the magnetic drift motion both in normal and tangential to the flux surfaces.



Neoclassical flux in a 3-species LHD plasma. Comparisons of FORTEC-3D (lines) with a local approximation code (points).



Local w/o magnetic drift | Local w/ magnetic drift | Global

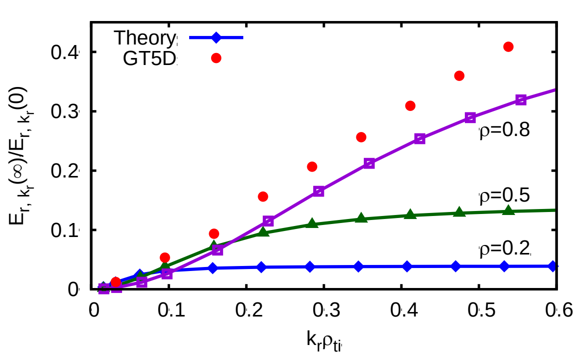
Difference in the potential variation Φ_1 on a flux surface in LHD plasma according to the drift-kinetic models.

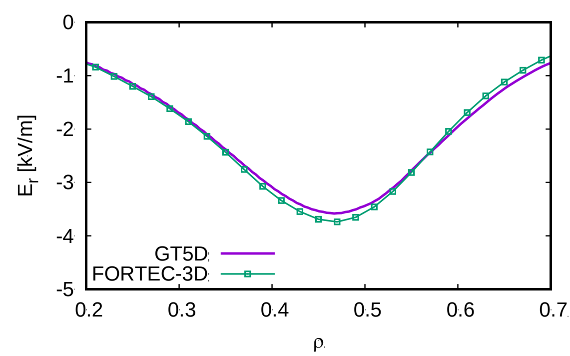
World's first trial of impurity NCT simulation in 3D configuration + global model

- FORTEC-3D is extended to multi-ions species plasmas, including the effect of potential variation on flux surface to study the impurity transport.
- Radially-local model (LOF3D) has been developed to clarify the effect of local approximation used in conventional neoclassical transport codes.

Global full-f kinetic simulation code, GT5D, has been extended to 3D heliotron/stellarator equilibria

- A global full-f gyrokinetic simulation code, GT5D, is extended to general 3D equilibria provided by VMEC with the aid of the new coordinate transformation under a collaborative research with JAEA.
- This work has been published by Physics of Plasmas as an Editor's pick, and also presented as an invited talk at 2nd Asia-Pacific Conference on Plasma Physcs.





- Residual level of the collisionless zonal flow damping shows a reasonable agreement with a theoretical prediction for outer radius (ρ=0.8).
- Neoclassical transport of another global neoclassical code (FORTEC-3D) has been recovered successfully.

Summary of research achievements in neoclassical and turbulent transport simulations

- The reduced models for particle and heat transport based on the gyrokinetic simulation for the kinetic electron condition are obtained for the integrated simulations by TASK3D.
- Based on collaborations with QST, a new global transport code TRESS+GKV is developed, and the both (multiple) ions and electron transport simulation framework is established.
- Nonlinear GKV simulations for LHD isotope plasmas reveals a significant isotope mass impacts on turbulence and zonal flows. Experimental trend of improved confinement is reproduced for LHD D-plasmas.
- The radial particle flux of carbon impurity caused by turbulence remains inward directed within wide ranges of the gradients. On the other hand, the neoclassical particle flux of the impurity can be outward with electron-root Er if there exists sufficient direct contributions of injected beam.
- A global full-f gyrokinetic simulation code, GT5D, is extended to general 3D equilibria provided by VMEC with the aid of the new coordinate transformation under a collaborative research with JAEA.

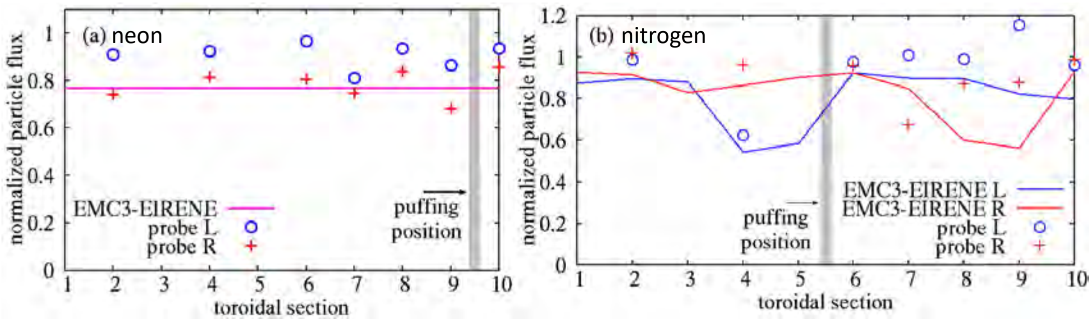
Peripheral plasmas & PWI

Simulations of peripheral plasmas and plasma-wall interaction for construction of Numerical Simulation Reactor

- Impurity transport simulation by 3D transport code EMC3-EIRENE
- 2-D electrostatic Particle-In-Cell code PICS2 for Plasma-Wall-Interaction
- Integration of Neutral-Transport Code, EMC3-EIRENE and MD Simulation to calculate molecular hydrogen in LHD plasmas.
- BCA-MD-KMC multi-hybrid simulation for formation of “Fuzz” under helium plasma irradiation
- Finite-Distance Time-Domain (FDTD) simulation on optical properties of Tungsten fuzz structure

Difference of transport characteristics of Ne and N has been revealed by modeling and experiment

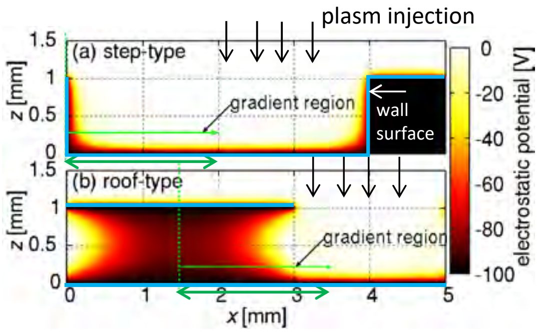
- Impurity transport in the impurity-seeded plasma is simulated by 3D transport code EMC3-EIRENE.
- Recycling coefficients of neon and nitrogen is modeled as 100% and 0%, respectively, according to their chemical activity on the divertor plates.

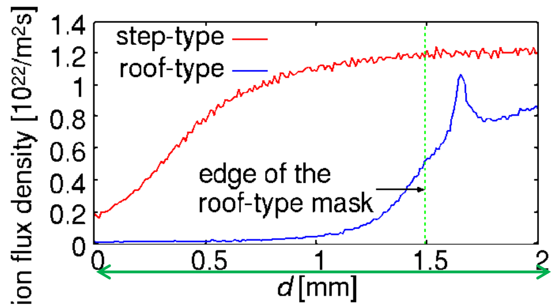


- Neon and nitrogen distributions in the plasma obtained by EMC3-EIRENE are toroidally symmetry and asymmetry, respectively.
- Toroidal distribution of particle flux is symmetry with neon seeding.
- On the other hand, the distribution is asymmetry with nitrogen seeding.
- The modeling reproduced the distributions obtained by Langmuir probes.

2-D electrostatic Particle-In-Cell code PICS2 has been developed for Plasma-Wall-Interaction researches

- A Particle-In-Cell (PIC) code has been developed and applied to the simulation of a plasma-exposure experiment of NAGDIS-II (Nagoya Univ.)
- The code is designed for modeling of magnetized sheath plasma with arbitrary surface shapes defined by multiple line segments.
- The code has high portability and available for collaborations.





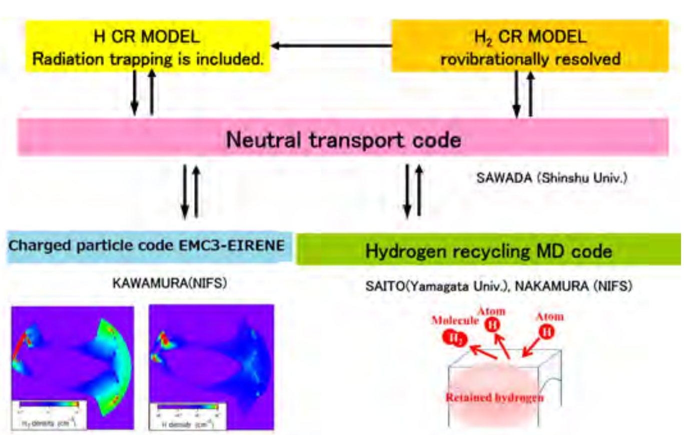
- Two types of surface geometries were simulated: (a) step and (b) roof.
- Wide range of flux variation was obtained with the roof type, and that is consistent with experimental results.

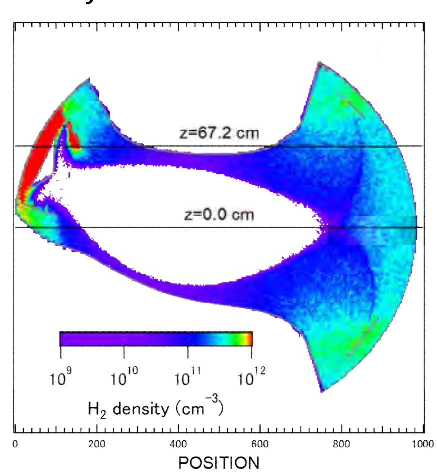
[G. Kawamura et al., Nucl. Mater. Energy 12 (2017) 297]

Rovibrational Population Calculation of Molecular Hydrogen in LHD Plasmas: Neutral-Transport Code, EMC3-EIRENE and MD Simulation.

Collaborate with Shinshu Univ., Yamagata Univ., Kyoto Univ.

- H_2 density distribution are calculated using Neutral-Transport code with H and H_2 data released from Divertor plate, which are simulated by MD-sim.



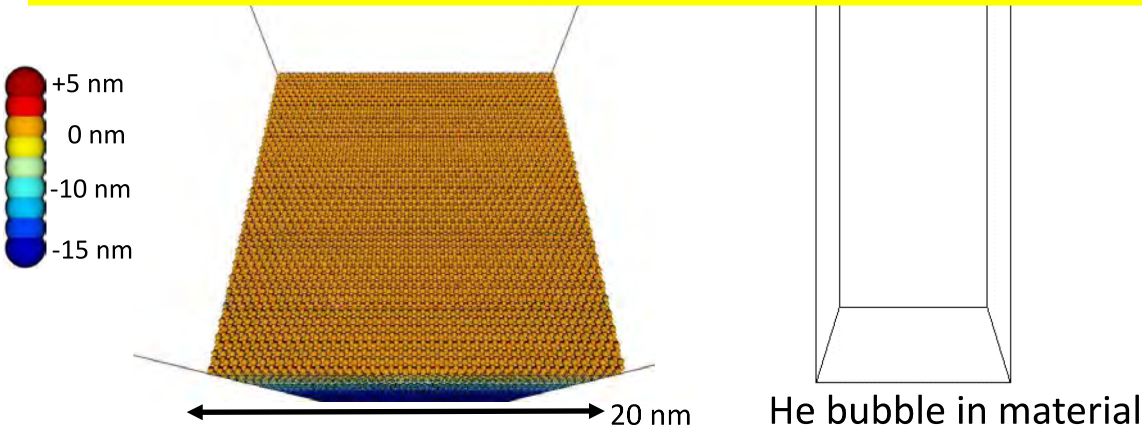


K. Sawada et al., 17th International Workshop on Plasma Edge Theory in Fusion Devices, 19-21 August, 2019, UCSD.

- Code integration of neutral transport code, charged particle code (EMC3-EIRENE) and the recycling model (MD) is successfully performed.
- H and H_2 density profile in LHD can be calculated using integrated code.

Formation of "Fuzz" under helium plasma irradiation is represented by BCA-MD-KMC multi-hybrid simulation

- BCA-MD-KMC multi-hybrid simulation solves
  - helium injection by using BCA (binary collision approx.)
  - helium diffusion by using KMC (kinetic Monte-Carlo)
  - tungsten deformation by using MD (molecular dynamics)



E_I=100eV, 1100K, Flux 1.4x10^{22}m^{-2}s^{-1}, Fluence 2.36x10^{23} m^{-2} (16.9s in time)

- The simulation achieved 100 sec. in elapse time for 40 day in calculation time.
- Helium bubble bursting generates surface roughness. After that, the sputtering and re-deposition of W atoms enhanced the growth tungsten fuzzy nanostructure.

Finite-Distance Time-Domain Simulation on Optical Properties of Tungsten Fuzz Structure

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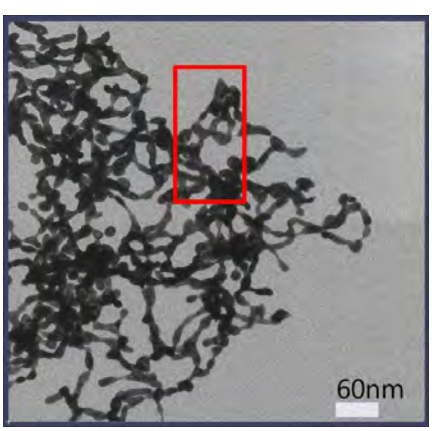
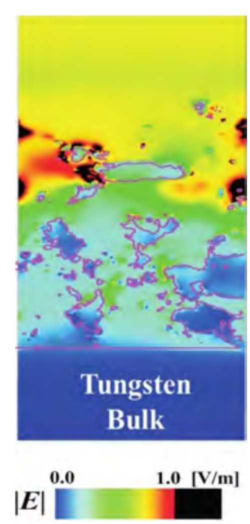
Collaborate with Nagoya Univ., Kushsu Univ., Kyushu Inist. Tech., NIFS

- 3D structure data of fuzz tungsten are obtained by electron tomography using transmission electron microscopy (TEM/ECT).
- Reflectance of fuzz can be calculated by FDTD simulation.





H.Nakamura et al., ISPlasma2018/IC-PLANTS2018, Meijo University, Nagoya, Japan. March 4-8, 2018

- We clarify a mechanism of the electromagnetic (EM) field absorption in the nano-structured tungsten quantitatively by the FDTD simulation.
- The nano-structures enhance the EM-field around them, and the enhanced EM-field generates the induced current in the tungsten surface.

Summary of research achievements in simulations of peripheral plasmas and plasma-wall interaction

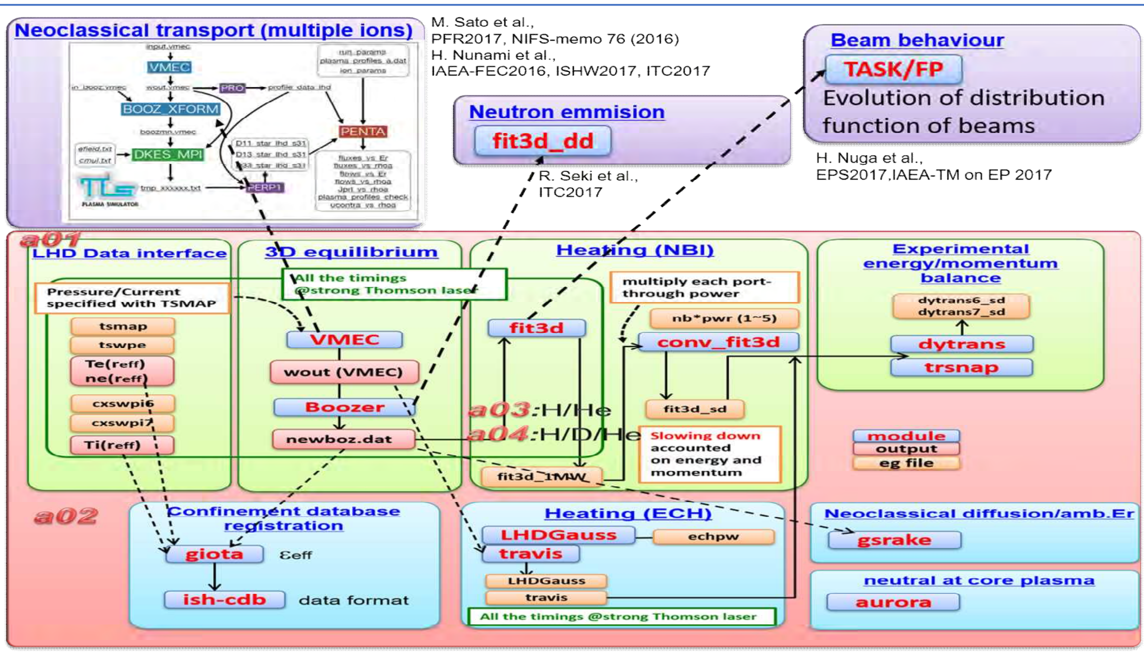
- Difference of transport characteristics of Ne and N is revealed by modeling and experiment.
- 2-D electrostatic Particle-In-Cell code PICS2 is developed for Plasma-Wall-Interaction researches.
- Neutral-Transport Code, EMC3-EIRENE and MD Simulation are integrated to calculate molecular hydrogen in LHD plasmas.
- Formation of “Fuzz” under helium plasma irradiation is represented by BCA-MD-KMC multi-hybrid simulation.
- A mechanism of the electromagnetic field absorption in the nano-structured tungsten is quantitatively clarified by the FDTD simulation.

Integrated code

Integrated Code and Collaboration with Fusion Engineering Research Project

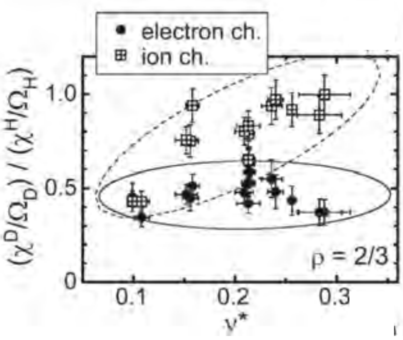
- Progress in TASK3D-a and TASK3D-p
- Applications of TASK3D-a to LHD deuterium experiment
- Implementation of Data Assimilation approach to TASK3D
- Application of TASK3D, FORTEC-3D, EMC3-EIRENE, and VR to helical reactor design studies

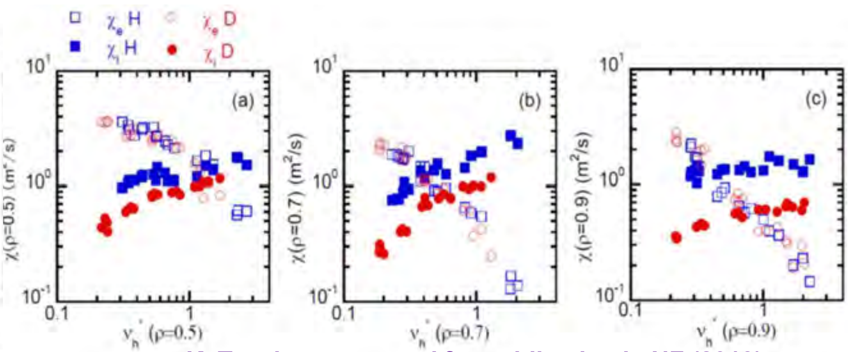
Extension of Integrated Transport Analysis Suite, TASK3D-a, for LHD Experiment Analyses



- Substantial progress made to be compatible with LHD deuterium experiment (**a03 and a04**, such as NBI module extension to include He and D).
- Loose coupling with large-scale simulation codes (such as **DKES/PENTA**).

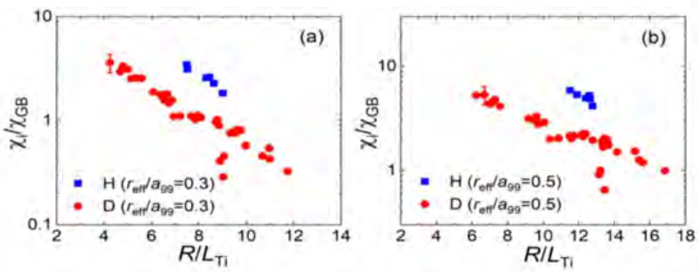
Applications of TASK3D-a to LHD deuterium experiment (1)



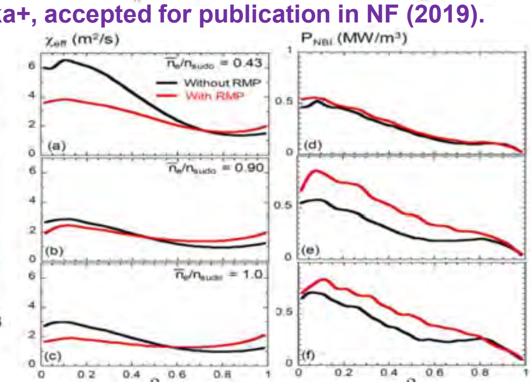


H. Yamada+, 27th IAEA FEC, EX/P3-5 (2018).
Accepted for publication in Phys. Rev. Lett. (2019).

K. Tanaka+, accepted for publication in NF (2019).



K. Nagaoka+, accepted for publication in NF (2019).



M. Kobayashi+, accepted for publication in NF (2019).

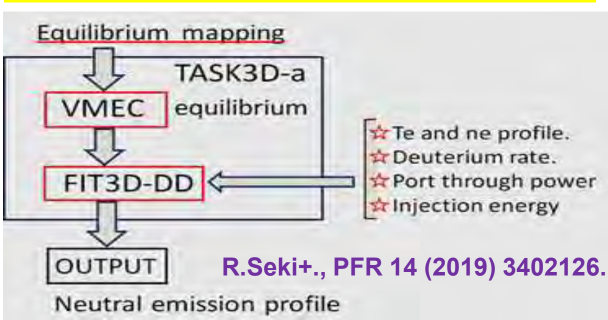
- Transport analyses database has been accumulated for studying isotope effect
- Contributions to many LHD experiment papers

Applications of TASK3D-a to LHD deuterium experiment (2)

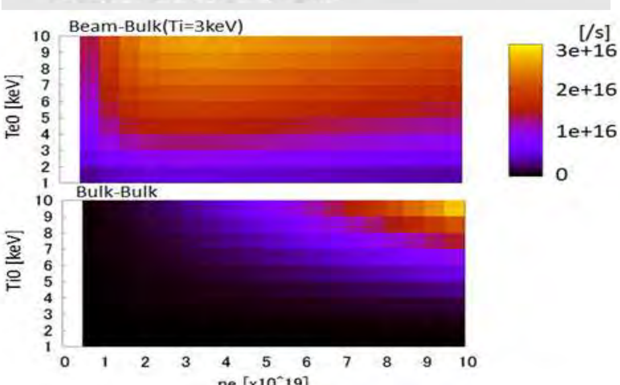
Development of (easy-to-use) **neutron emission calculation tool** (daily used for LHD experiment planning) based on **TASK3D-a**

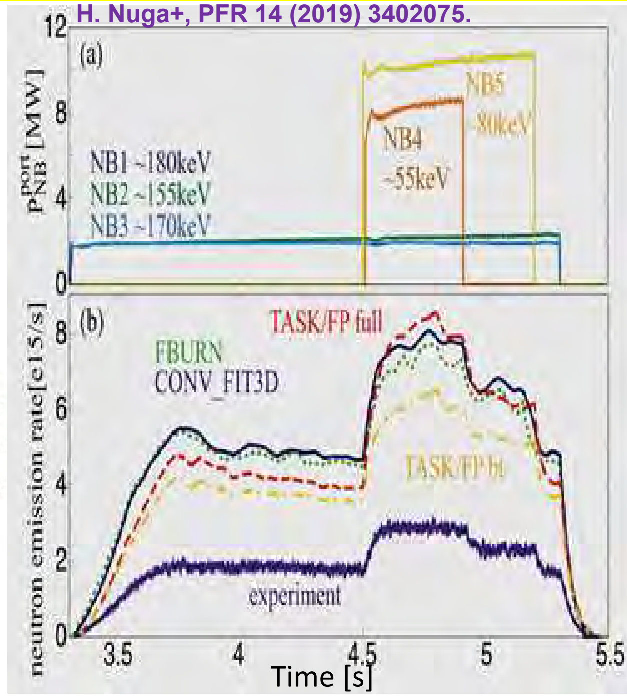
Benchmark of **codes for neutron emission calculation (CONV_FIT3D, FBURN, TASK/FP)** based on **TASK3D-a**

H. Nuga+, PFR 14 (2019) 3402075.



R.Seki+., PFR 14 (2019) 3402126.





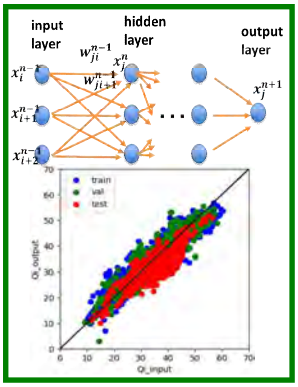
FBURN : K. Ogawa+, PPCF 60 (2018) 095010

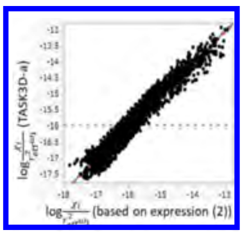
Progress made in predictive version, TASK3D(-p)

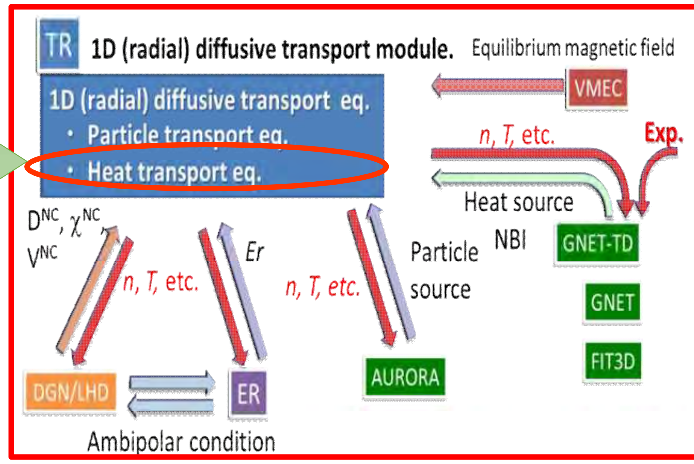
Extension of transport models (χ) → Ranging comparison and validation can be possible (towards acquiring "relevant" model)

- Gyro-Bohm, Gyro-Bohm x ∇T
- Zeff, Aeff model
- Neural-Network based
  (S. Maeta, (Kyoto U., D3), submitted to J. Fusion Energy (2019).)
- Statistical induction (M. Yokoyama, Nucl. Fusion 59 (2019) 094004.)

Link to "Data-driven Science"







Implementation of *Data Assimilation* approach (TASK3D)

- **Data assimilation**: Optimizing a numerical model with observations (by replacing variables, constants and initial values of the model with probability distributions (state space model)
- Successfully employed in **weather/oceanic** area ⇒ **implementation to TASK3D for fusion research** (collaboration established among **Kyoto U., The Institute of Statistical Mathematics (ISM) and NIFS)**

Courtesy of Y. Morishita (Kyoto U., M2)

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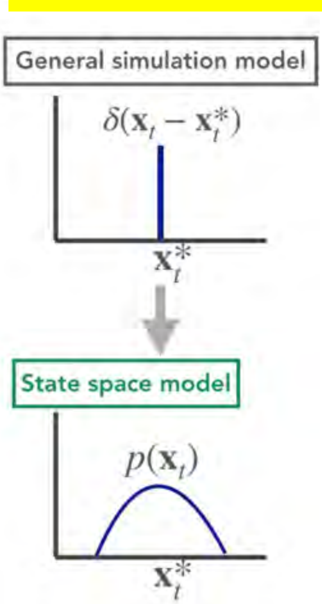
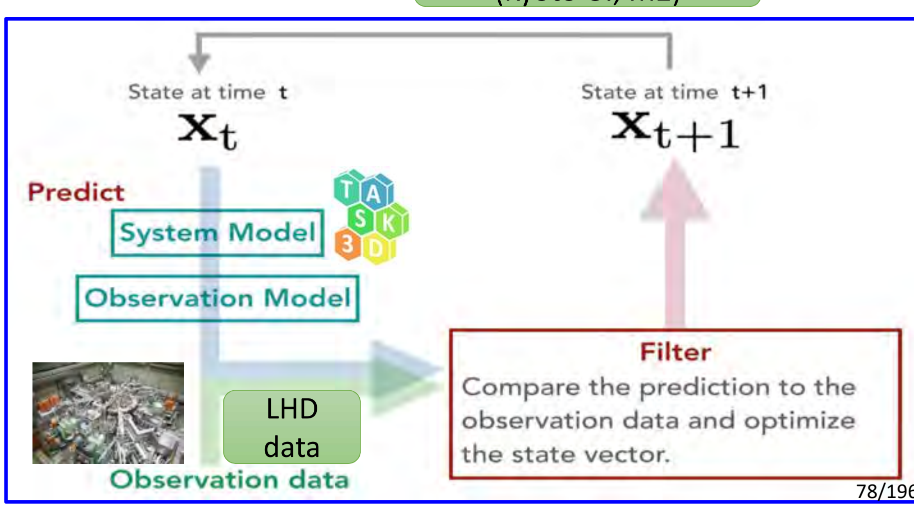
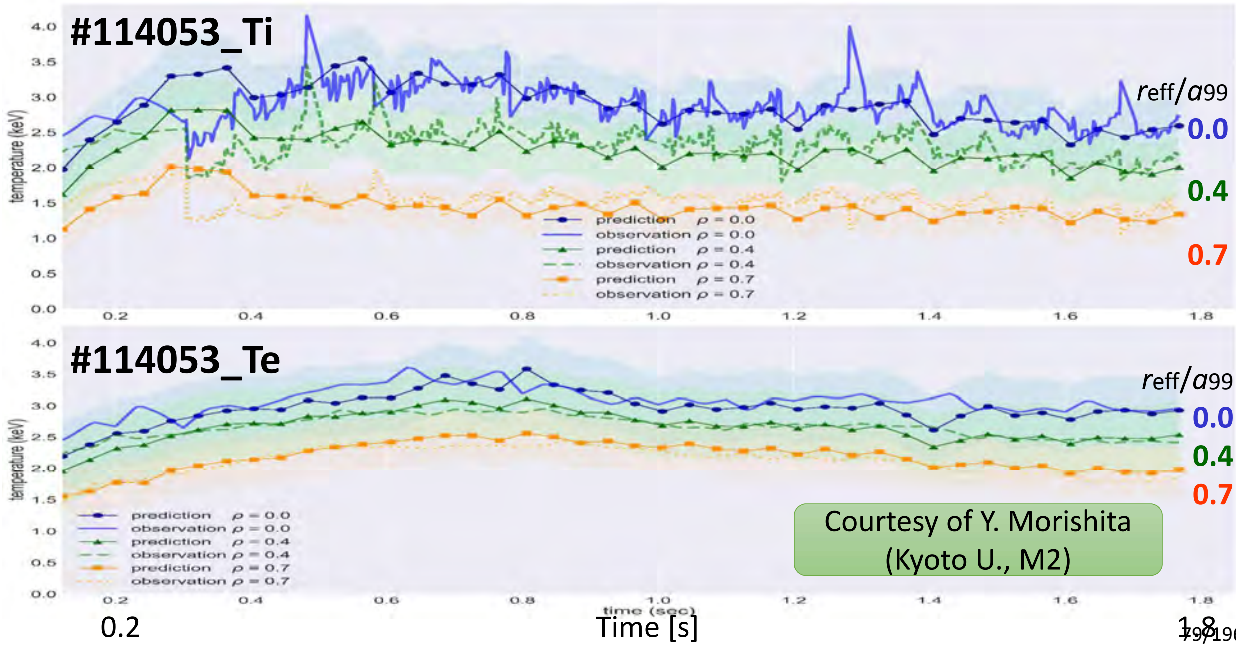




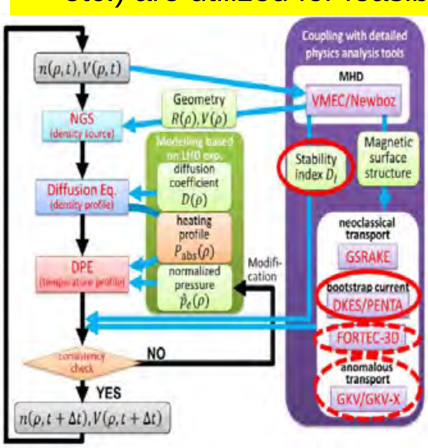
Implementation of Data Assimilation approach (TASK3D)

- Implementation done, an example case was successfully executed (time window of ~ 2 s performed), and then the relevant paper was submitted.
- Physics interpretation of “optimized model”, application to other discharges etc., are foreseen.

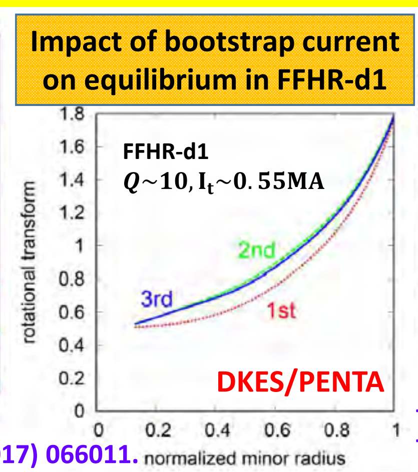


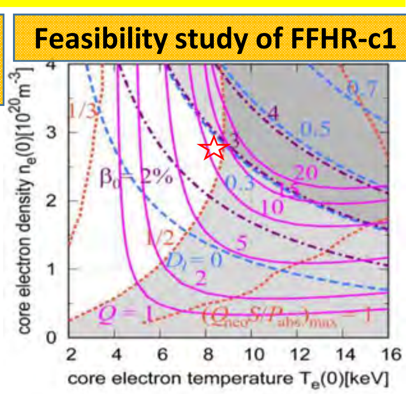
Collaborations with Fusion Engineering Research Project (FERP) have been deepening and expanding (1)

- In the collaboration with FERP, **TASK3D-a** and other kinetic codes (**FORTEC-3D** etc.) are utilized for feasibility study of helical reactor design FFHR-d1 and -c1.



T.Goto et al., NF 57 (2017) 066011.



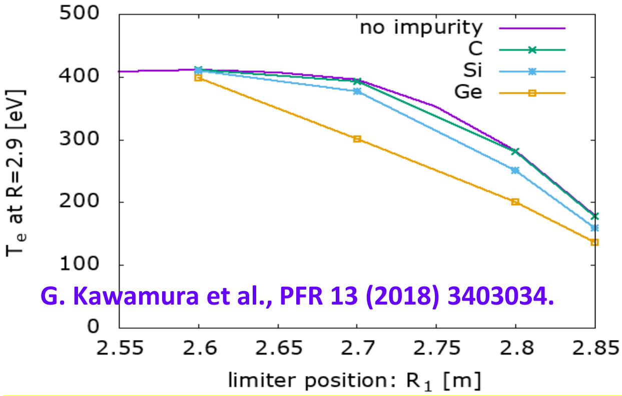


T.Goto et al., IAEA-FEC 2018 FIP/P7-39.
T. Goto et al., NF 59 (2019) 076030.

- Q~10 steady-state operation scenario of FFHR-d1 was sought by 1D transport analysis tools. In particular, the impact of bootstrap current on MHD equilibrium was evaluated by iterating MHD and neoclassical calculations.
- Feasible study of compact (R_{ax}~11 m) reactor FFHR-c1 was carried out using **TASK3D-a** modules, which turns out to predict Q=10~15 operation point.

Collaborations with Fusion Engineering Research Project (FERP) have been deepening and expanding (2)

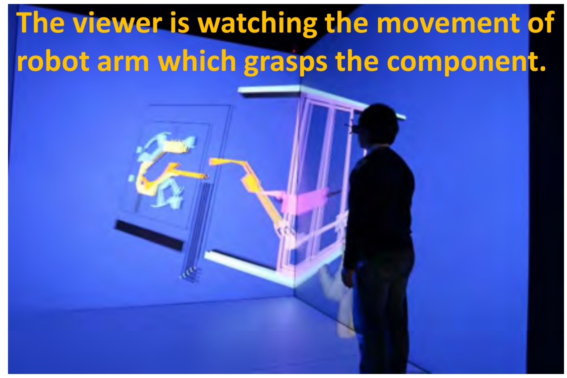
Impact of a liquid divertor, REVOLVER-D, on impurity behaviour



G. Kawamura et al., PFR 13 (2018) 3403034.

- Influence of a limiter (resembling REVOLVER-D) was evaluated by using **EMC3-EIRENE** code.
- Decrease of core T_e is caused by the limiter placed deeply in the plasma.
- Impurity with higher atomic number has stronger impact on the plasma. Sn data is not available, but its influence is thought to be larger than Ge.

VR visualization of reactor design CAD data



- The CAD design data of future reactor was visualized in **VR system**.
- Component interference, installation and detachment of components, and movements of robot arm etc. can be checked from any viewpoints.

Summary of research achievement: Integrated Code and Collaboration with Fusion Engineering Research Project

- TASK3D-a is extended by coupling to DKES/PENTA and NBI module for analyses of LHD deuterium experiment.
- TASK3D-p is extended by incorporating new transport models.
- Data Assimilation approach is successfully implemented to TASK3D.
- TASK3D and FORTEC-3D are utilized for design study of FFHR.
- EMC3-EIRENE code and VR sytem support fusion engineering studies.

[2]-(2)

2. Research achievements

Does the NSRP produce high-level achievements in accordance with international standards for the following research areas described in the third midterm goal and plan by promoting theory and computer simulation research utilizing the Plasma Simulator?

(2) Academic systematization of fusion science and related science and engineering

NSRP has produced high-level achievements in theory and computer simulation research contributing to academic systematization of fusion science and related science and engineering in the following areas:

- PIC simulations of magnetic reconnection, magnetic sonic waves, impurity ion transport, and ICF plasma.
- Studies of two-fluid tearing instability, interchange/tearing instabilities, and Hall MHD turbulence.
- Advanced visualization technology
- Systematization through publishing a textbook and review papers

Research achievements in particle simulations

- Development of electromagnetic particle simulation code, PASMO
- Magnetic reconnection
- Magnetic sonic waves
- Impurity ion transport
- ICF plasma.

Development of PASMO

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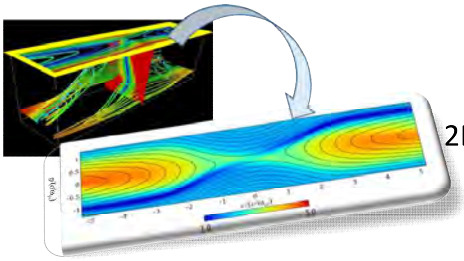
- The PASMO code is a electromagnetic (EM) particle simulation code.
- 2DPASMO is 2D3V EM PIC code. It focuses survey on the physics such as acceleration and heating in a reconnection plane.
- 3DPASMO is three-dimensional (3D) EM PIC code. It can analyze 3D dynamics in the reconnection.

3DPASMO



2DPASMO

- Dynamical load balance library "OhHelp" is implemented to 3DPASMO.
- Optimization for thread parallelization is applied to 3DPASMO.
- Domain decomposition with MPI is also implemented to 2DPASMO.
- These optimization will increase simulation size of reconnection.

The electromagnetic particle simulation code PASMO was optimized for thread and distributed parallelization

- The random memory access takes place during the gather and pusher processes.
- If the simulation domain is decomposed uniformly, a load balance problem may appear when the number density of particles are not uniform.
- The PASMO code was optimized from the viewpoints of a distributed memory and multi-processor computer system.

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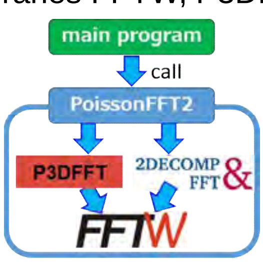
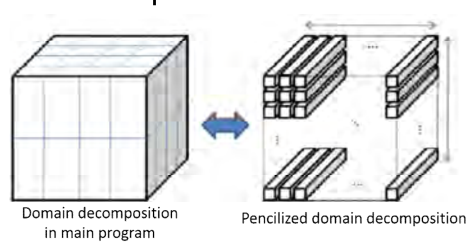
- We exchanged the particle data array, implemented the bucket sorting and the sort process of particles in the particle data array, inserted the directive “schedule(dynamic)”, and changed loop structure, in order to access the memory continuously. As a result, the elapsed time decreased by 53.9% compared to the original code.
- In order to solve the load imbalance, we implemented the OhHelp library, which had the dynamic load-balancing algorithm by making each computation node help another heavily loaded node, to the PASMO code. As a result, the elapsed time decreased compared to the original code in some simulation conditions.

3D parallelized Poisson solver library “PoissonFFT2” has been developed and will be provided for PS users

- **PoissonFFT2** has been developed by NIFS and Fujitsu and is adaptable to the 3D/2D domain decomposition, that is, 3D/2D distributed data.
- In PoissonFFT2, the parallelized multi-dimensional fast Fourier transform (FFT) libraries FFTW, P3DFFT, and 2Decomp&FFT are used.





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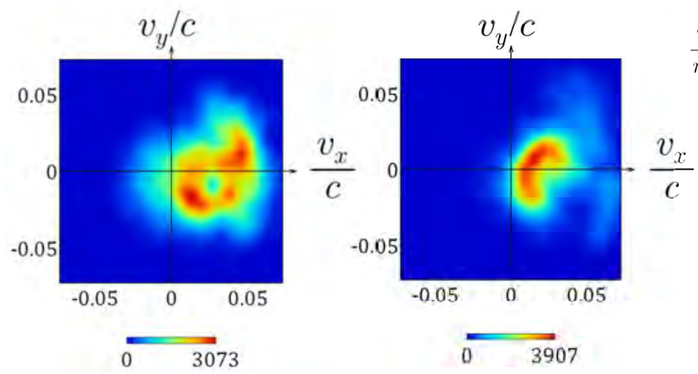
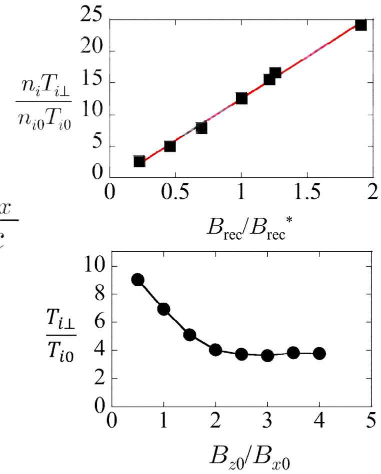
- PoissonFFT2 transforms 3D distributed data into 2D/1D distributed data because the FFT libraries are not adaptable to 3D distributed data.
- PoissonFFT2 can solve both the differential equation form and the difference equation form of Poisson equation and can apply the smoothing function and periodic, Dirichlet, and Neumann boundary conditions.
- PoissonFFT2 has been installed into PASMO, up3bd, and extended-MHD codes, will be opened within a few years, and will be provided for Plasma Simulator users who need a parallelized Poisson solver library.

PASMO simulations have revealed the mechanism of ion effective heating during magnetic reconnection.

- During driven magnetic reconnection, a ring-shaped or an arc-shaped velocity distributions of ions are formed in the downstream. This means that ions are effectively heated.





- The ion heating energy (density x temperature) is proportional to the square of the reconnection (poloidal) magnetic field, while the ion temperature is lower as the guide (toroidal) magnetic field.
- The two tendencies are in good agreement with experimental results in STs

Parallel electric field in nonlinear magnetosonic wave in three-component plasmas has been theoretically analyzed

- The particle simulations showed that the electric field parallel to the magnetic field in a magnetosonic shock wave plays crucial roles in particle acceleration mechanisms that can be applied to production of energetic particles in space and astrophysical plasmas.

- In this study, the parallel electric field $E_{\parallel}$ and its integral F along the magnetic field in nonlinear magnetosonic wave in three component plasmas (two-ion-species plasma and electron-positron-ion plasma) have been theoretically analyzed with attention to the frequency range $\Omega_i \ll \omega \ll \Omega_e$.

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The maximum values of F have been derived as

$$eF_{\mathrm{M}} \sim \epsilon^2 m_i v_{\mathrm{A}}^2$$ two-ion-species plasma

$$eF_{\mathrm{M}} \sim \epsilon^2 \frac{n_{i0}/n_{e0}}{(1+n_{p0}/n_{e0})^2} m_i v_{\mathrm{A}}^2$$ electron-ion-positron plasma

ϵ : wave amplitude n_{e0}, n_{i0}, n_{p0} : densities of electron, ion, and positron

These are much greater than F_{M} for the frequency range $\omega \ll \Omega_i$.
The theory can explain the strong particle acceleration shown by the simulations.

Particle simulation codes for study of kinetic dynamics in boundary layer plasmas have been developed

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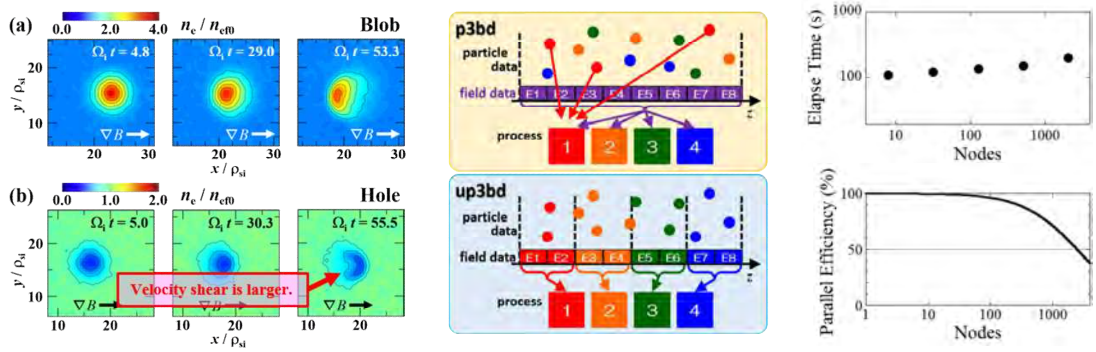
- 3D electrostatic PIC codes for study of filament dynamics (**p3bd** / **up3bd** codes) have been improved and developed.
- 1D electrostatic PIC-MCC code for study of detachment dynamics (**PAMCADE**) has been developed.



- The procedure of setting “hole” structure has been installed into p3bd code.
- up3bd code has been developed with the domain decomposition in the basis of p3bd code.
- In up3bd code, PoissonFFT2 library and in-place bucket sort are applied.
- up3bd code shows better scalability and performance than p3bd code.

3D effect of particle motion on plasma filament dynamics has been revealed with the PIC simulation

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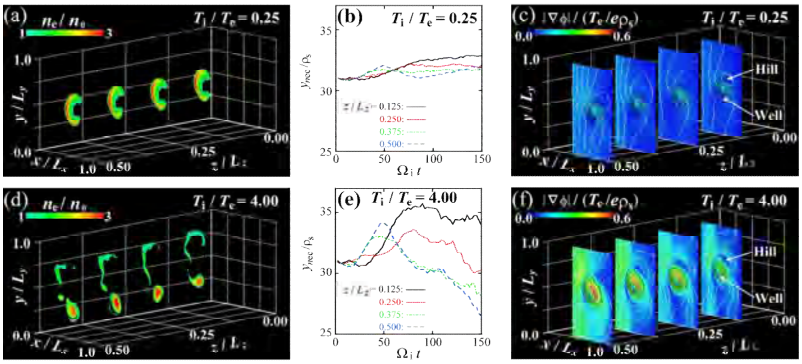
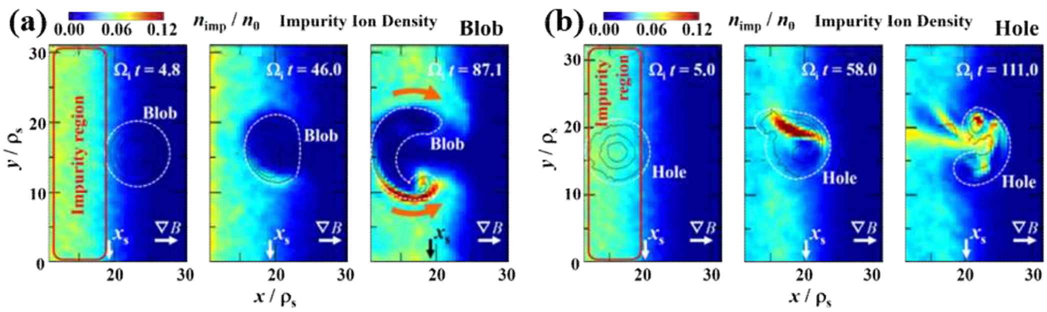
- This study has demonstrated kinetic behaviors on the plasma filament propagation with the p3bd code.
- It is shown for the first time with the p3bd code that the plasma particle motion influences plasma filament dynamics three-dimensionally.



- The poloidal symmetry breaking in the filament propagation occurs in the high T_i case and significantly depends on the toroidal position.
- The large pre-sheath drop on the hill side induces the strong dependence of the perpendicular electric field in the filament on the toroidal position.
- Such a 3D structure of the electric field influences the filament dynamics.

Impurity ion transport by plasma filaments has been investigated with the PIC simulation

- It is shown for the first time with the p3bd code that the plasma filaments transport impurity ions.
- This study might be able to explain the difference of impurity transport property between tokamak and helical devices.



- The blob penetrates to the impurity ion region and sweeps impurity ions.
- The impurity ions which surround the blob are transferred in the grad-B direction.
- The hole moves from the impurity ion region and carries impurity ions in the grad-B direction.

Dependence of the impurity ion transport by a plasma filament on various parameters has been investigated

- The dependence of the impurity ion transport by a plasma filament on various parameters has been studied with the p3bd code.
- This study suggests that the statistics regarding the size of filaments generated in devices are important for estimating the effect of filaments on the total impurity ion transport and that the impurity ion transport by filaments is not negligible in the high ion temperature plasma.

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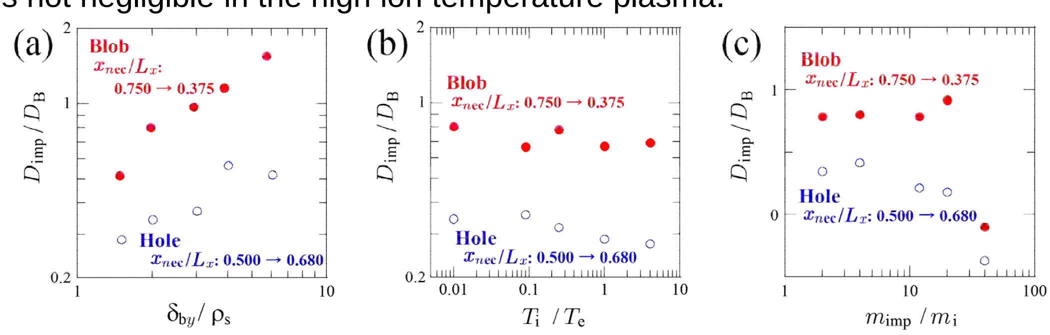

- The effective diffusivity of impurity ions
  1) has a positive correlation with the filament poloidal size,
  2) has a slight inverse correlation with the ion temperature, and
  3) becomes quite small in the heavy impurity ion mass case.

Isotope influences on the filament dynamics have been investigated with the PIC simulation

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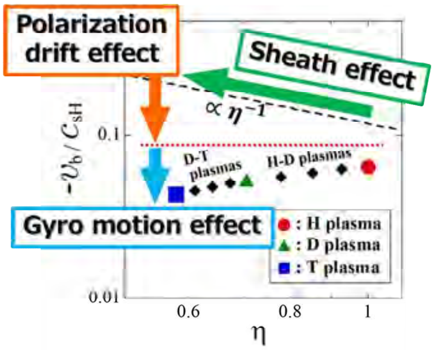
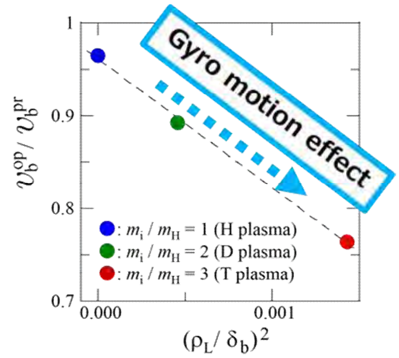
- The ion inertial influences, i.e., the isotope influences, on the sheath-limited filament dynamics have been investigated with the p3bd.
- In this study, the isotope influences in the polarization drift effect and the sheath effect are evaluated.

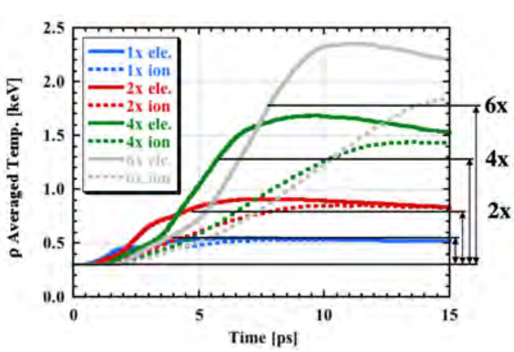


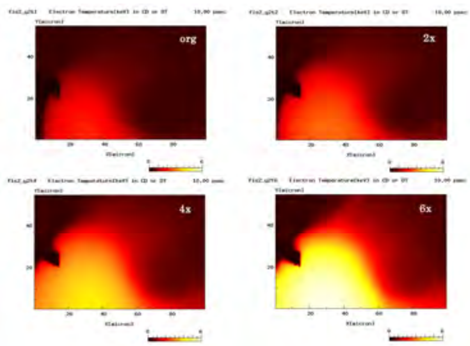


- The sheath effect expected by the conventional static estimation for a sheath-limited filament is cancelled out by the polarization drift effect in deuterium-tritium (D-T) plasmas.
- The radial propagation speed of a filament becomes slightly slower in D-T plasma than in light hydrogen (H) plasma because of the gyro motion effect.

As a preliminary work, an energy boost of the heating laser has been modeled in ion assisted fast ignition

- The ion assisted fast ignition scheme is suggested, where low-density CH foam is introduced as a ion beam generator, and additional core heating by proton (H^+) and carbon (C^{6+}) beams is expected.
- Integrated simulations, in which particle data in 2D PIC *fiscof2* code are transferred into the source term in 2D core heating *fibmet2* code, are carried out to evaluate the core heating properties.





- The density averaged electron temperatures increase more than extension factors of the total energy, but energy relaxation is not enough.
- Electrons near the injection point are heated more than 5 keV, but core electrons are not heated so much.

Research achievements in studies of

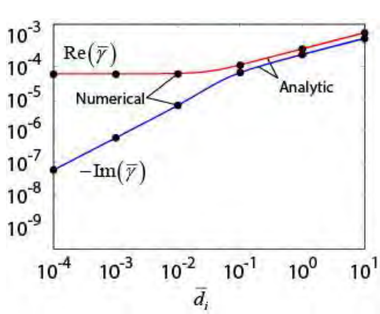
two-fluid tearing instability

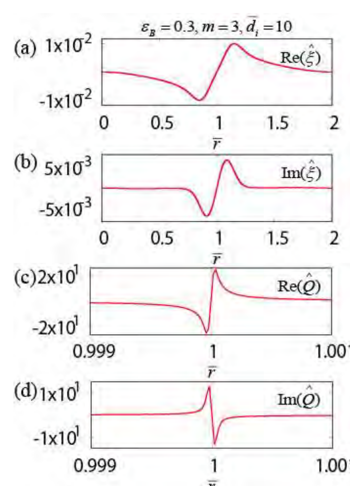
interchange/tearing instabilities

and Hall MHD turbulence.

Growth rate and eigenfunctions for two-fluid tearing instability become complex in cylindrical geometry

- The two-fluid resistive tearing mode instability in a periodic plasma cylinder of finite aspect ratio is investigated numerically.
- Research collaboration with MIT

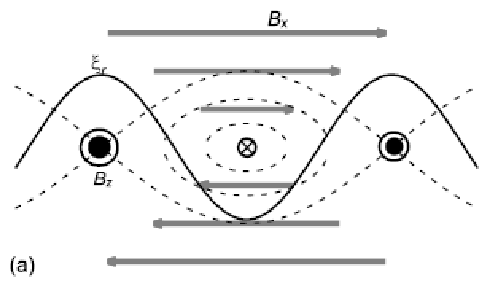


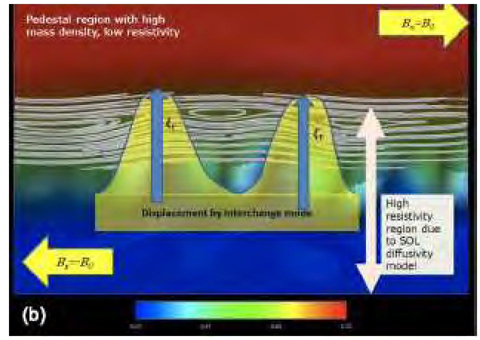


- The real and imaginary parts of the growth rate and the eigenfunctions become comparable when parameters such that the cylindrical aspect ratio and two-fluid effects are of order unity.

Interchange/tearing instabilities in 2D slab with a numerical model for edge plasma

- Numerical simulations of interchange/tearing instabilities in a 2D slab with a numerical model foredge plasma resistivity are carried out by the use of MUTSU/MINOS code. (Collaborative work with IFS UT Austin by JIFT program.





- A numerical model with current diffusivity is developed to enforce a low level saturated current profile in the SOL region as well as a current jump across the LCFS.
- The numerical simulations (b) show that interchange modes can transform into tearing modes, as the current-interchange tearing modes (a) which has been proposed by Zheng and Furukawa (2010).

The modulational parity instability is one of the mechanisms of parity mixture in interchange modes.

[M. Sato and A. Ishizawa, Phys. Plasmas (2017)]

- Nonlinear formation of magnetic islands in resistive interchange modes has been investigated by two-fluid reduced MHD simulations.

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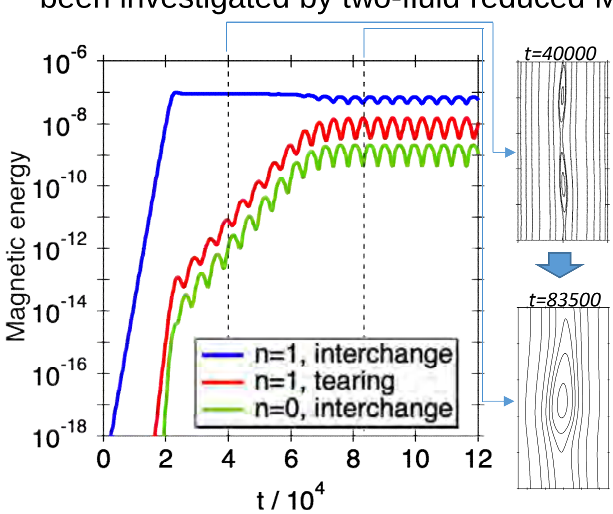
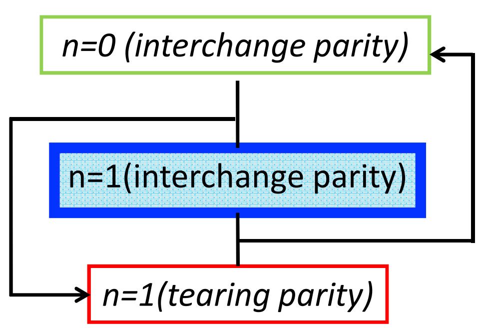
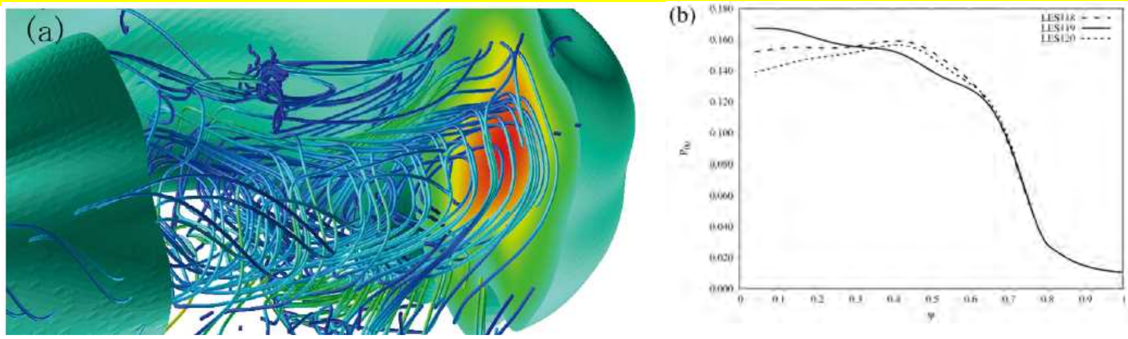




- A saturated state of the interchange mode is unstable against the tearing parity mode. This instability is called as the modulational parity instability where the pump mode is the interchange mode, and the side-band mode corresponds to the tearing parity mode representing the magnetic island formation.

3D Extended MHD Large Eddy Simulations of Ballooning Instability in LHD

- Large Eddy Simulation (LES) approach has been introduced to solve extended MHD (XMHD) equations numerically for studying nonlinear evolution of ballooning instability in LHD.
- Our LES (by the use of MUTSU/MINOS code) successfully reproduce basic nature of ballooning instability in LHD and show importance of sub-grid-scale effects in numerical simulations.



- (a) Diamagnetic flow is induced in LES of XMHD of R_{ax}=3.6m inward-shifted LHD plasma (β_0=3.6%) and move on to nonlinearly saturated state.
- (b) By a parameter study for SGS model of LES, we can see that plasma core can be stable for a stronger SGS effect.

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Development of MUTSU-T3 code

- A new pseudo-spectral simulation code, MUTSU-T3 code, has been developed for a study based on an extended MHD model.
- The new simulation code makes use of P3DFFT, FT3D, and FFTE 3d Fast Fourier Transform codes as well as VISMO in-situ visualization library.

Figure 1

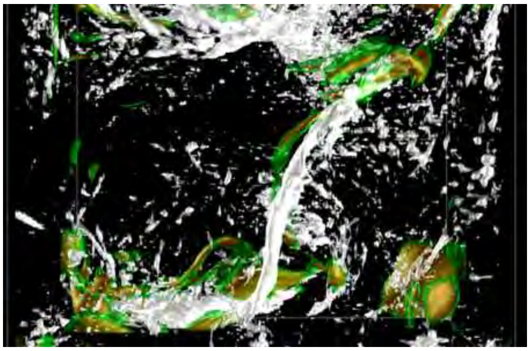
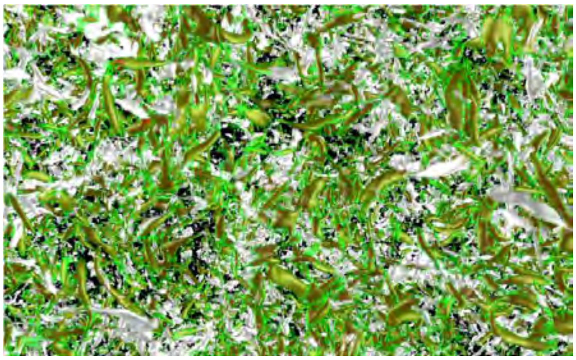


Figure 2



- The new code has been used for a study of homogeneous and isotropic turbulence of Hall MHD (Fig.1) and extended MHD models (Fig.2).
- Numerical simulations together with VISMO library shows effectiveness of in-situ visualization.

Development of SGS model for LES of XMHD based on DNS of Hall MHD turbulence

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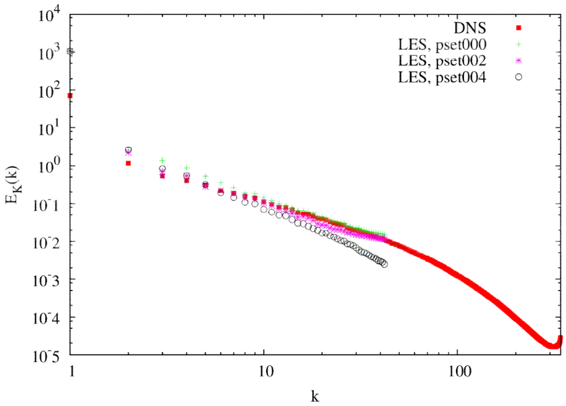
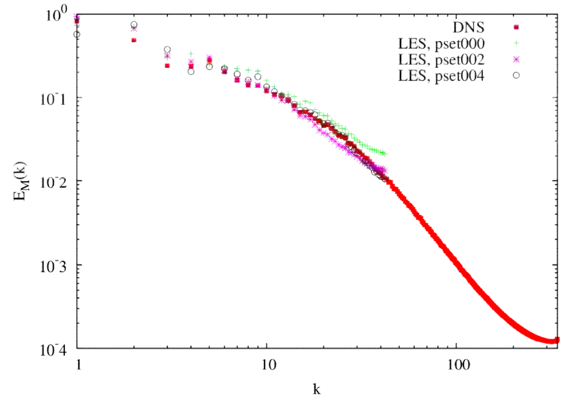
- SGS model required for LES of extended MHD (XMHD) has been developed based on DNS of Hall MHD turbulence.
- LES with our SGS model, by the use of MUTSU-T3/XMHD3D successfully reproduce turbulent energy spectra of Hall MHD turbulence.





- SGS model contains effects of flow shear and current density in the grid scale.
- Kinetic and magnetic energy spectra, $E_K(k)$ and $E_M(k)$, of DNS by $N^3=1024^3$ is well reproduced by LES of $N^3=128^3$.

Research achievements in VR visualization

The CAD data of future fusion reactor was visualized in VR space.

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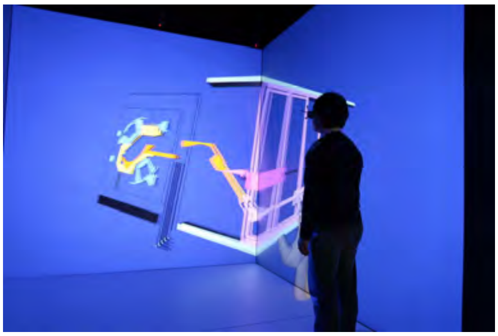
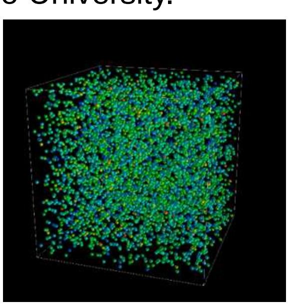
- It is important to design a reactor while considering previously how to assemble the components, because it will be possible to build up the reactor efficiently. The fusion reactor is designed to replace the components periodically in the fusion operation, and it is necessary to give consideration to the replacement process in advance.



- CompleXcope visualized the CAD data of future fusion reactor.
- The viewer can come into the reactor and confirm the design. It is possible to watch the movement of the components as animated graphics in the VR space. The viewer can also grasp the component by his virtual hand in the VR space.

In-situ visualization library “VISMO” is developed.

- In-situ visualization library VISMO is developed to couple the simulation code with the visualization code, and to perform visualization process together with simulation on the same supercomputer. The VISMO has also a function which generates point-cloud data for interactive visualization.
- This study is based on the collaboration framework between NIFS and Hyogo University.



- The new function was implemented to VISMO. The particles are visualized with color which can shows the physical valuable, for example, the particle velocity. The radius of particle can also be changed.
- The point cloud data is visualized by CompleXcope.

The visualization contents developed by “Unity”

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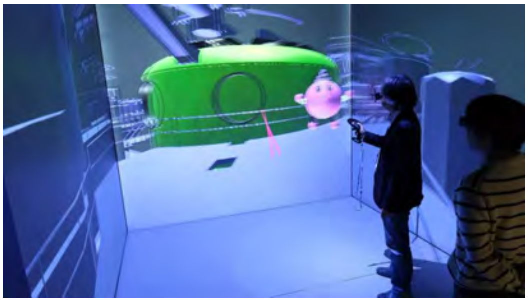
- Many kinds of visualization devices are introduced in the world, that is, head mount display, smartphone, CAVE, and so on.
- It become difficult to develop the visualization application in accordance with the visualization devices.
- We implemented a game development engine “Unity”.



- The CAD data of the periphery devices of LHD can be easily installed to the VR visualization content “LHD vessel”.
- The VR visualization content “LHD vessel” can be easily implemented to the head mounted display system.
- This study is based on the collaboration framework between NIFS and Hyogo University and JAMSTEC.

The application of Visualization technology to the other research field.

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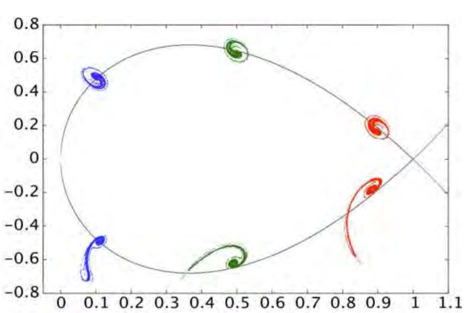
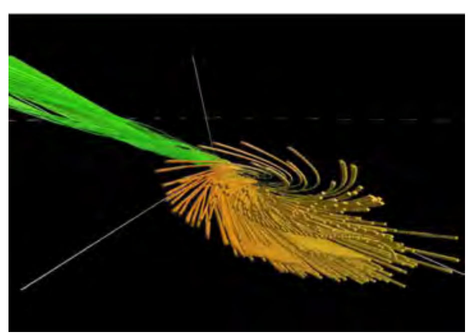
- The unique chaotic structure was found in uniform and anisotropic universe model by solving the Einstein equation.
- In usual analysis in chaos structure, the Poincare map is used.



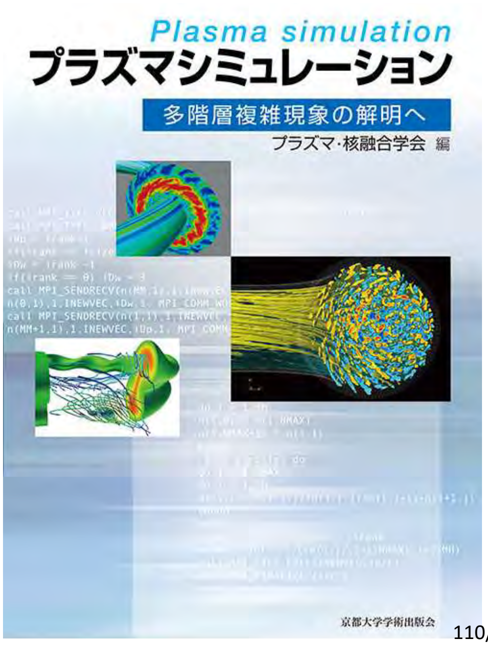


- In order to analyze the whole structure of the chaos, we visualized the orbit data in three dimensional space.
- It was found that each orbit rotated spirally.
- This study is based on the collaboration framework between NIFS. Osaka Prefecture University and Texas University at Austin.

Systematization through publishing a textbook and review papers

NSRP contributes to contributes to theoretical systemization of fusion plasma physics through publishing a textbook on plasma simulation (in Japanese) 「プラズマシミュレーション 多階層複雑現象の解明へ」

- Basic principles of plasma physics and numerical simulation are explained targeting undergraduate, graduate students, and researchers as readers.
- Recent results from state-of-the-art simulations of fusion and space plasmas are illustrated.
- 7 of 15 authors are from NIFS.
- Published from Kyoto Univ Press in Dec. 2018
- A5 format, 7 chapters, 400 pages



NSRP contributes to theoretical systemization of fusion plasma physics through publishing many review papers

Project review:

"Numerical Simulation Reactor Research Project at the National Institute for Fusion Science"

1. Introduction

- R. Horiuchi, J. Plasma Fusion Res. Vol. 92, 785 (2016) [in Japanese]

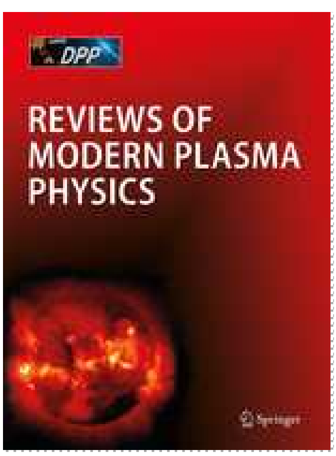
2. Simulation Researches in Fusion Plasmas

- K. Ichiguchi *et al*., "2.1 *MHD Equilibrium and Stability,*" J. Plasma Fusion Res. Vol. <u>92</u>, 787 (2016) [in Japanese]
- R. Kanno *et al*., "2.2 *Transport Simulation of Core Plasmas,*" J. Plasma Fusion Res. Vol. <u>92</u>, 794 (2016) [in Japanese]
- Y. Todo *et al*., "2.3 *Physics of Energetic Particles, Waves and Heating,*" J. Plasma Fusion Res. Vol. <u>92</u>, 806 (2016) [in Japanese]
- K. Suzuki *et al*., "2.4 *Peripheral Plasma Transport and Plasma-Wall Interaction,*" J. Plasma Fusion Res. Vol. <u>92</u>, 810 (2016) [in Japanese]
- M. Yokoyama, "2.5 *Development of the Integrated Transport Analysis Code,*" J. Plasma Fusion Res. Vol. <u>92</u>, 814 (2016) [in Japanese]

3. Sophistication of Computational Science and Fundamental Physics Simulations

- S. Ishiguro *et al*., J. Plasma Fusion Res. Vol. <u>92</u>, 821 (2016) [in Japanese]

NSRP contributes to theoretical systemization of fusion plasma physics through publishing many review papers



H. Sugama,

"*Modern gyrokinetic formulation of collisional and turbulent transport in toroidally rotating plasmas*,"

Rev. Mod. Plasma Phys. 1:9 (2017)

[downloaded 1,500 times, as of Nov. 2019]

Y. Todo,

"*Introduction to the interaction between energetic particles and Alfven eigenmodes in toroidal plasmas*,"

Rev. Mod. Plasma Phys. 3:1 (2019)

[downloaded 1,600 times, as of Nov. 2019]

H. Sugama,

"*Momentum Transport, Electric Field Formation, and Symmetry under Parity Transformation in Torus Plasmas*,"

J. Plasma Fusion Res. <u>92</u>, 539 (2016) [in Japanese]

H. Sugama and the Numerical Simulation Reactor Research Project Group,

"*Recent Progress in the Numerical Simulation Reactor Research Project*,"

Plasma Fusion Res. <u>14</u>, 3503059 (2019) [Overview Article]

NSRP contributes to theoretical systemization of fusion plasma physics through publishing many review papers

"Simulation of Magnetically Confined Fusion Plasma by Integrated Code and Its Prospect"

J. Plasma Fusion Res. 95, 423 (2019) [in Japanese]

NIFS staff

1. "Development of Integrated Code for Fusion Plasma Simulation,"
   N. Hayashi, A. Fukuyama, S. Murakami, M. Yokoyama, T. Fujita
2. "Physics Modules Constituting Integrated Code,"
   S. Murakami, M. Honda, N. Aiba, A. Matsuyama, N. Hayashi, K. Hoshino, T. Fujita, A. Fukuyama, M. Yokoyama
3. "Status of Integrated Code Development in Japan and Overseas,"
   A. Fukuyama, N. Hayashi, S. Murakami, M. Yokoyama, T. Fujita
4. "Application of Integrated Code: Experiment Analysis, Physics Understanding and Development of Operation Scenario,"
   M. Yokoyama, S. Satake, M. Honda, N. Aiba, N. Hayashi, M. Yagi, T. Fujita, S. Murakami, R. Seki, H. Yamaguchi, H. Nuga
5. "Future Prospects of Integrated Code Development,"
   M. Honda, E. Narita, N. Hayashi, M. Yagi, A. Fukuyama, S. Murakami, M. Yokoyama, T. Fujita
6. "Conclusion and Acknowledgements,"
   N. Hayashi, A. Fukuyama, S. Murakami, M. Yokoyama, T. Fujita, M. Honda

Advanced formulation of drift and gyro-kinetic equations for collisional and turbulent transport simulation

skip

- A novel radially local drift kinetic equation that includes both ExB and tangential magnetic drift terms is derived. It is written in the conservative form and has favorable properties for numerical simulation that any additional terms for particle and energy sources are unnecessary for obtaining stationary solutions [H. Sugama, S. Matsuoka, S. Satake, and R. Kanno, Phys. Plasmas 23, 042502 (2016)].
- A novel gyrokinetic formulation is presented by including collisional effects into the Lagrangian variational principle to yield the governing equations for background and turbulent electromagnetic fields and gyrocenter distribution functions, which can simultaneously describe classical, neoclassical, and turbulent transport processes in toroidal plasmas with large toroidal flows. The particle, energy, and toroidal momentum balance equations are given in the conservative forms, which are desirable properties for long-time global transport simulation [H. Sugama, M. Nunami, M. Nakata, and T.-H. Watanabe, Phys. Plasmas 24, 020701 (2017)].
- The Eulerian variational principle for kinetic plasma equations in a general coordinate system is presented. The invariance of the action integral under an arbitrary spatial coordinate transformation is used to obtain the momentum conservation law and the symmetric pressure tensor in a more direct way than using conventional methods [H. Sugama, M. Nunami, S. Satake, T.-H. Watanabe, Phys. Plasmas 25, 102506 (2018)].

Improved linearized model collision operator for the highly collisional regime is presented

skip

- The improved model is constructed so as to give exactly the same friction-flow relations as those derived from the linearized Landau operator, and accordingly it can be used to accurately evaluate neoclassical transport fluxes in all collisional regimes.
- In addition, the improved collision operator for gyrokinetic equations is derived by taking the gyrophase average with the finite gyroradius effect taken into account.
- The improved model operator is useful for kinetic simiulation to investigate transport processes of impurity ions such as tungsten in future LHD and ITER plasmas.

Field particle part of the linearized model collision operator

$$C_{ab}^F(\delta f_b) = -\mathbf{V}_{ab}[\delta f_b]\cdot C_{ab}^T(f_{aM} m_a \mathbf{v}/T_a) - W_{ab}[\delta f_b] C_{ab}^T(f_{aM} x_a^2) + \Delta C_{ab}^F(f_{b1})$$

Correction term

$$\Delta C_{ab}^F(f_{b1}) \equiv f_{aM}\frac{m_a}{T_a}\mathbf{v}\cdot\sum_{j=1}^{\infty}\Delta\mathbf{C}_{abj}^F[f_{b1}] L_j^{(3/2)}(x_a^2)$$

$$\Delta\mathbf{C}_{abj}^F[f_{b1}] \equiv \frac{c_j}{\tau_{ab}}\sum_{k=1}^{\infty}\Delta N_{ab}^{jk}\,\mathbf{u}_{bk}[f_{b1}] \quad (j = 1, 2, \cdots)$$

H. Sugama *et al*., Phys. Plasmas **26**, 102108 (2019)

[2]-(3)

2. Research achievements

Does the NSRP produce high-level achievements in accordance with international standards for the following research areas described in the third midterm goal and plan by promoting theory and computer simulation research utilizing the Plasma Simulator?

(3) Are research achievements steadily made according to the plan of the NSRP?

NSRP has produced high-level achievements according to the third midterm plan.

- Advance researches for developing and integrating simulation codes
  - Model core turbulent transport and apply it into integrated transport code
  - Incorporate multiple ion species effects into transport codes
  - Improve MD simulation for PFM
- Validate simulation codes by comparison with experimental results
- Conduct simulation researches on related basic physics
- Promote domestic and international collaborations including ITER
- Improve the performance of the Plasma Simulator during FY2019 (maintaining the joint use rate of Plasma Simulator at 100%)

Research achievements made according to the plan of NSRP (1)

- Effectively use Plasma Simulator for construction of the Numerical Simulation Reactor to advance the researches for the development, the extension, the high precision, and the integration of the 3D simulation codes
  → Extension of global GK codes (GT5D & XGC-S) for helical systems (PoP2018, IAEA2018, ISHW2019, Plasma2019)
  - Combining kinetic thermal ion simulation with MHD (IAEA2018, NF2019, ISHW2019)
  - Integration of Neutral-Transport Code, EMC3-EIRENE & MD simulation for molecular hydrogen in LHD (PET2019).
- Model turbulent transport in core plasma and apply the model into the integrated transport code by the end of FY2019
  → χ_i, χ_e & quasilinear flux models based on GK simulation (PoP2019)
  - Application of χ_i, χ_e models to TASK3D for LHD (PFR2019)
  - TRESS+GKV for a tokamak (Plasma Conference 2017)
- Incorporate multiple ion species effects into various transport codes
  → Multiple ion species incorporated into GKV (PPPCF2017), GNET (NF2016), TASK3D (NF2017), FORTEC-3D (submitted to CPC)
- Develop molecular dynamics simulation techniques and build new models necessary for evaluating physical properties of plasma facing materials such as tungsten
  → BCA-MD-KMC multi-hybrid simulation of tungsten fuzzy nanostructure (PFR2018)

Research achievements made according to the plan of NSRP (2)

- Improve the code accuracy by comparison with the experimental results on the three-dimensional equilibrium, transport, instability and nonlinear evolution of magnetically confined plasmas including LHD plasmas
  → Validation of MIPS (NF2017), MEGA (NF2016, 2019, PoP2017, PRL2018), GKV (PPCF2016, 2019, PRL2017, ISHW2017, EPS2018, NF2016, 2019), FORTEC-3D (PoP2018), EMC3-EIRENE (NME2017), TASK3D (NF2017) against LHD, JT60U, DIII-D, W7X, Heliotron J, EAST, NAGDIS-II, RELAX, …

- Conduct simulation researches on related basic physics
  → PIC simulations of magnetic reconnection (PoP2019),
  magnetic sonic waves (PFR2018),
  impurity ion transport (NF2017, PoP2019), and ICF plasma (JoP:CS2016)
  - Studies of two-fluid tearing instability (PoP2018),
  interchange/tearing instabilities (PoP2017),
  LES of Hall MHD turbulence (JCP2016)
  - Advanced visualization (JSST2018 Outstanding Presentation Award)

Research achievements made according to the plan of NSRP (3)

- Promote domestic and international collaborations including ITER
  → See the next chapter [3].
- Improve the performance of the Plasma Simulator more than four times compared to the current system during FY2019
  → Plasma Simulator is to be upgraded in June 2020.
  From survey of technology trends, one year delay from the original schedule was decided to achieve the target performance.
- Maintain the joint use rate of Plasma Simulator at 100%.
  → The joint use rate of Plasma Simulator has been maintained at 100%.

The NSRP has produced many high-level achievements in accordance with international standards

Selected in Nucl. Fusion Highlights 2016
Y. Todo et al., Nucl. Fusion 56, 112008 (2016)
Fast ion profile stiffness due to the resonance overlap of multiple Alfvén eigenmodes

Selected as Editor's Pick of Phys. Plasmas
S. Matsuoka et al., Phys. Plasmas 25, 022510 (2018)
Neoclassical transport benchmark of global full-f gyrokinetic simulation in stellarator configurations

Ranked 12th of Top 15 Most Downloaded Articles in the past year from Phys. Plasmas
S. Toda et al., Phys. Plasmas 26, 012510 (2019)
Modeling of turbulent particle and heat transport in helical plasmas based on gyrokinetic analysis

Achievements during 2016-2019

Item	Number
Refereed Journal Papers	266
PRL / Nature Comm / Sci Rep	3 / 2 / 1
PoP / NF / PPCF	37 / 60 / 24
Invited presentations at international conferences except IAEA-FEC	44
Presentations at IAEA-FEC 2016 & 2018 (oral)	83 (18)
Invited presentations at domestic conferences	10
Awards to NSRP members of NIFS	10

Research achievements disseminated through EurekAlert (AAAS)

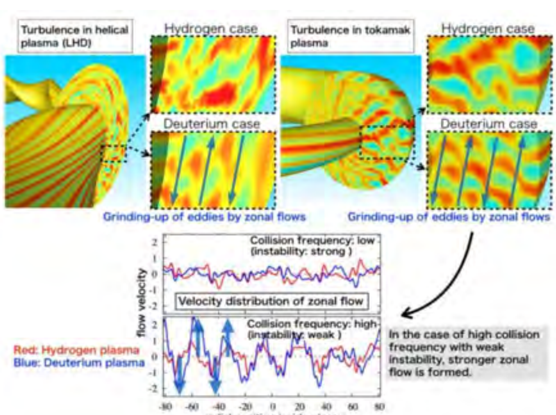
EurekAlert! AAAS

PUBLIC RELEASE: 24-APR-2017

Clarifying the mechanism for suppressing turbulence through ion mass

Theoretical research develops significantly towards improved performance in fusion plasmas

NATIONAL INSTITUTES OF NATURAL SCIENCES



CREDIT: DR. MOTOKI NAKATA

NEWS RELEASE 6-AUG-2019

Simulations demonstrate ion heating by plasma oscillations for fusion energy

NATIONAL INSTITUTES OF NATURAL SCIENCES

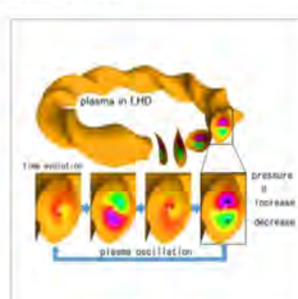


IMAGE: PLASMA OSCILLATIONS DRIVEN BY HIGH-ENERGY PARTICLES IN A PLASMA IN LHD. view more ›

CREDIT: NIFS

Research achievements disseminated through EurekAlert (AAAS)

EurekAlert! AAAS

PUBLIC RELEASE: 30-JUN-2017

How do impurities move in tungsten?

Automatic and high-speed search on migration paths by using a supercomputer

NATIONAL INSTITUTES OF NATURAL SCIENCES

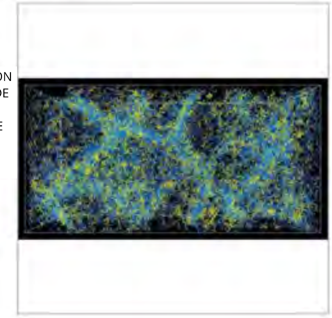


IMAGE: THE SIMULATION RESULT IS BASED UPON THE DYNAMIC MONTE CARLO METHOD4). INSIDE THE BASE MATERIAL OF THE TUNGSTEN, THE ATOMS OF WHICH STRUCTURE IS CLOSE TO THE CRYSTAL ARE NOT... **view more ›**

CREDIT: DR. ATSUSHI M. ITO

PUBLIC RELEASE: 24-NOV-2016

Clarifying the plasma oscillation by high-energy particles

Developing new simulation methods

NATIONAL INSTITUTES OF NATURAL SCIENCES

IMAGE: LHD HIGH-ENERGY PARTICLES CIRCULATE INSIDE A PLASMA THAT IS SHAPED LIKE A TWISTED DOUGHNUT, AND THEY CAUSE PLASMA OSCILLATIONS. IN PARTICULAR, WHEN THE PERIOD OF THE CIRCULATION AND THAT OF... **view more ›**

CREDIT: DR. YASUSHI TODO

PUBLIC RELEASE: 21-DEC-2016

Calculating 1 billion plasma particles in a supercomputer

Clarifying the movements of a plasma blob at the particle level

NATIONAL INSTITUTES OF NATURAL SCIENCES

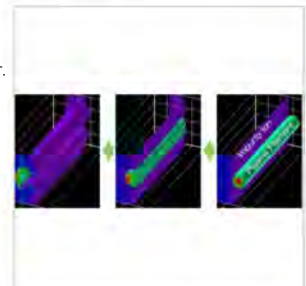


IMAGE: TIME IS PASSING FROM RIGHT TO LEFT. THE TUBE IN GREEN IS THE SURFACE OF THE PLASMA BLOB. AREAS WHERE IMPURITIES ARE GREAT ARE IN BLUE AND AREAS WHERE IMPURITIES... **view more ›**

CREDIT: DR. HIROKI HASEGAWA

Research achievement disseminated through newspapers

Clarifying the mechanism for suppressing turbulence through ion mas

岐阜新聞

2017年（平成29年）4月22日 土曜日 29

プラズマ 1億度超え

核融研の重水素実験 発電実用化へ前進

高温、高密度化の仕組み解明

日刊工業新聞

31 | 4月12日・水曜日 2017年（平成29年）

乱流抑制機構を解明

イオン質量 プラズマで影響大

核融合科学研など

【名古屋】核融合科学研究所の仲田資季助教と名古屋大学理学研究科の渡辺智彦教授らは、イオン質量による乱流抑制のメカニズムを解明した。高密度で高性能なプラズマではイオン質量の影響が大きく、電子とイオンの衝突が生み出す作用によって乱流が抑制されるという。

軽水素プラズマより重水素プラズマが高性能になるイオン質量効果の全容解明にもつながる。

乱流はプラズマの熱や粒子の閉じ込めを劣化させるが、プラズマの中の電子とイオンの衝突が不安定性を抑える働きをする。この働きはイオン質量が大きい重水素プラズマの方が軽水素プラズマに比べて顕著であり、乱流を抑制しやすい。

不安定性が弱くなった状態では、一定間隔で流れの向きが反転する帯状流が強くなって乱流をさらに抑え、熱や粒子の閉じ込めを改善する。

メカニズムの解明は核融合炉のプラズマの高性能化にもつながる。

東濃新報

2017年（平成29年）4月14日（金） (2)

プラズマ性能解明が進展

核融合科学研究所

スパコンで乱流を模擬実験

あいさつする竹入所長

Research achievements disseminated through newspapers

Application of VR to fusion reactor design

PIC simulation of plasma heating by magnetic reconnection

PIC simulation of coherent structure in peripheral plasma

[3]-(1)

3. Promotion of cooperation and collaborations

(1) Is collaboration research with universities based on theory and simulation research appropriately promoted? Does it contribute to the progress of the NSRP?

(2) Does the NSRP contribute to enhancing functions of universities and institutes as the center of excellence for fusion plasma simulation? Does the NSRP commit to the promotion of interdisciplinary collaboration and research?

(3) Does the NSRP contribute to international cooperation including ITER, BA activities, and others through international collaboration activities?

NSRP promotes collaboration research by integrating the high capabilities of universities and institutes for making progress of NSRP.

- NSRP cooperation program has accepted about 60-70 research subjects involving about 180 collaborators each year.
- The Plasma Simulator Symposium provides collaborators with opportunities for the exchange of research information.
- Collaborators from universities and institutes join and support the NSRP task groups to enhance the project research activities.

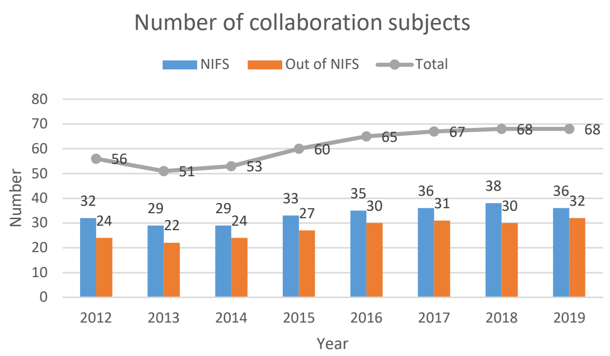
skip

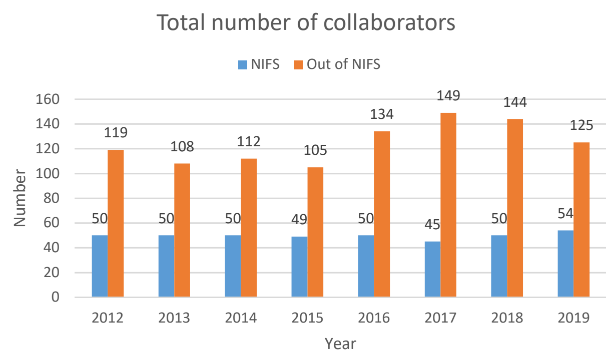
Framework of the general collaboration research programs at NIFS relating to NSRP

Three categories in NIFS collaboration programs regarding to theory and numerical simulation

1. Theory collaboration research
   - Programs proposed by NIFS
   - Programs proposed by domestic collaborators
2. Plasma Simulator collaboration research
   - Programs proposed by NIFS
   - Programs proposed by domestic collaborators
3. Collaboration research utilizing the LHD Numerical Analysis Server

NSRP collaboration program has accepted about 60-70 research subjects involving about 180 collaborators each year

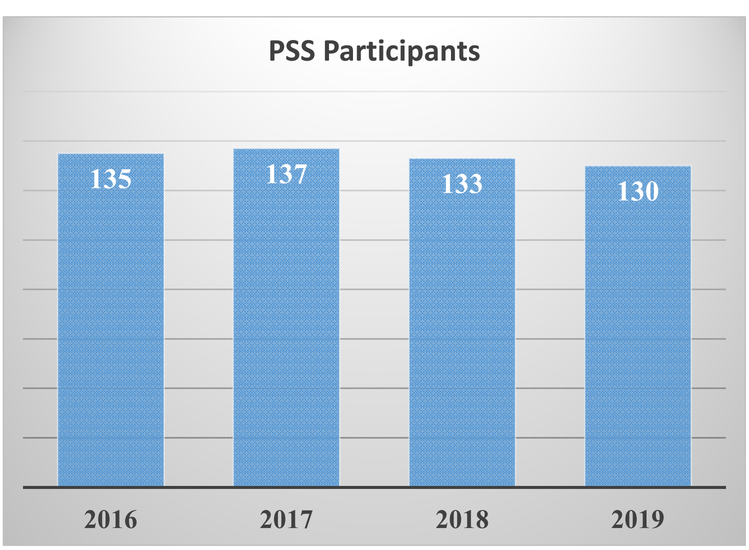


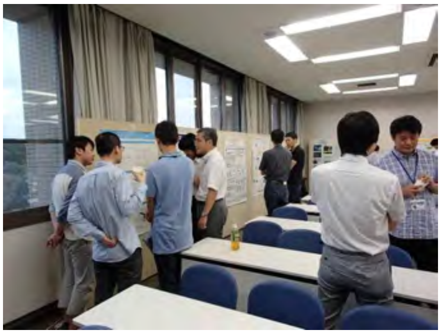


- The number of accepted collaboration subjects is approximately 60-70.
- The total number of collaborators in the accepted subjects is approximately 180 each year, including 50 from NIFS and 130 from universities.

Plasma Simulator Symposium provides collaborators with exchange of research information

- Plasma Simulator Symposium (Simulation Science Symposium) has been held for the “Plasma Simulator” users to report recent numerical results, and also to introduce recent topics in large-scale numerical simulations in various fields, to the users.





Many collaborators from universities and institutes join the NSRP task groups to make progress of NSRP

group	leader	member
Plasma fluid equilibrium stability	K. Ichiguchi	13（sim. 7, exp. 3, collab. 3）
Energetic-particle physics	Y. Todo	9（sim. 4, exp. 3, collab. 2）
Integrated transport simulation	M. Yokoyama	28（sim. 4, exp. 13, collab. 11）
Neoclassical and turbulent transport simulaton	R. Kanno	16（sim. 8, exp. 3, collab. 5）
Peripheral plasma transport	Y. Suzuki	20（sim. 4, exp. 5, collab. 11）
Plasma-wall interaction	H. Nakamura	18（sim. 4, exp. 3, collab. 11）
Multi-hierarchy physics	H. Miura	18（sim. 12, collab. 6）
Simulation science basis	H. Ohtani	16（sim. 12, exp. 1, collab. 3）

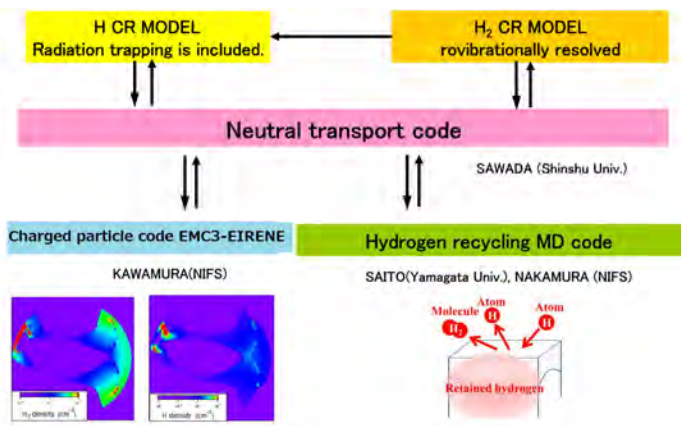
Sim.: simulation staff, exp.:experiment staff, collab.:domestic collaborators

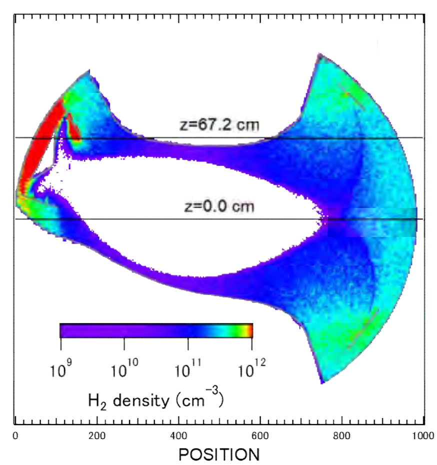
- Many collaborators from other projects and from outside NIFS have joined these task groups to enhance collaboration and cooperation studies.
- Most of the simulation staff in the NSRP also participate in other task groups.

Rovibrational Population Calculation of Molecular Hydrogen in LHD Plasmas: Neutral-Transport Code, EMC3-EIRENE and MD Simulation.

Collaborate with Shinshu Univ., Yamagata Univ., Kyoto Univ.

- H_2 density distribution are calculated using Neutral-Transport code with H and H_2 data released from Divertor plate, which are simulated by MD-sim.





K. Sawada et al., 17th International Workshop on Plasma Edge Theory in Fusion Devices, 19-21 August, 2019, UCSD.

- Code integration of neutral transport code, charged particle code (EMC3-EIRENE) and the recycling model (MD) is successfully performed.
- H and H_2 density profile in LHD can be calculated using integrated code.

Collaborations on EMC3-EIRENE:
1. Tungsten transport and redeposition in LHD
2. Divertor footprint in JT-60SA with RMP field

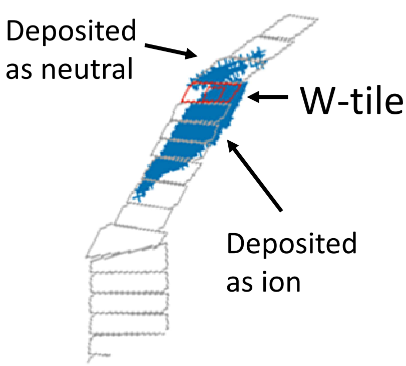
Collaborate with 1) Keio Univ. 2) Nagoya Univ. , QST. and Keio Univ.

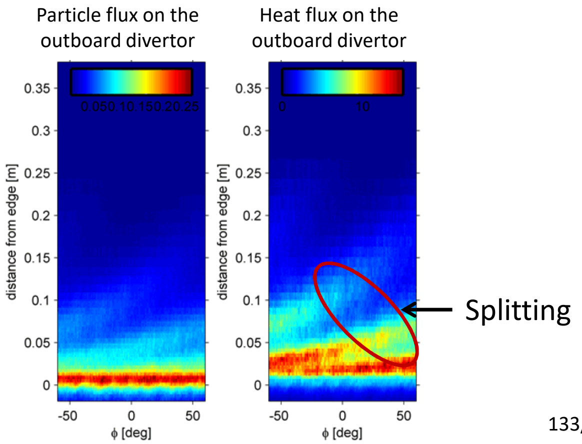
1. Tungsten (W) transport from a W-tile to the neighboring tiles are simulated by IMPGYRO code with a background plasma obtained by EMC3-EIRENE code.

- Redeposition patterns of W characterized by neutral atoms and ions were found on different regions.

2. Divertor footprint in JT-60SA with RMP field was obtained for the first time by EMC3-EIRENE code.

- Splitting of the flux distribution was obtained corresponding to the toroidal mode number of the RMP field.

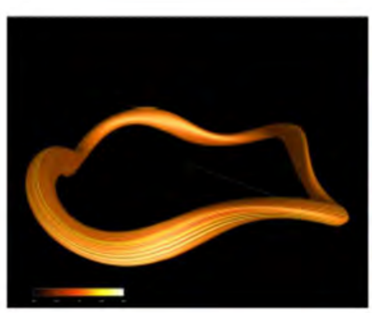


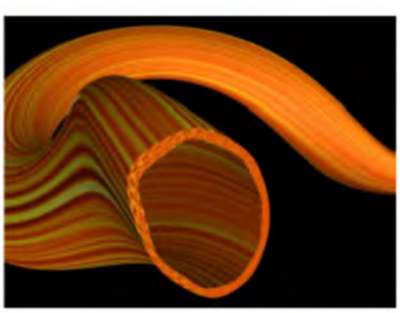


Collaboration with Kyoto University on gyrokinetic simulation of turbulent transport in helical systems

- Drift-wave instability and nonlinear turbulent transport are investigated in two configurations with different magnetic field structures (LHD and Heliotron J) by means of electromagnetic gyrokinetic simulations
  [A. Ishizawa, Y. Kishimoto, T.-H. Watanabe, H. Sugama, K. Tanaka, S. Satake, S. Kobayashi, K. Nagasaki, and Y. Nakamura, "*Multi-machine analysis of turbulent transport in helical systems via gyrokinetic simulation*," Nucl. Fusion 57, 066010 (2017)]

ITG turbulence (electrostatic potential) in Heliotron J plasma





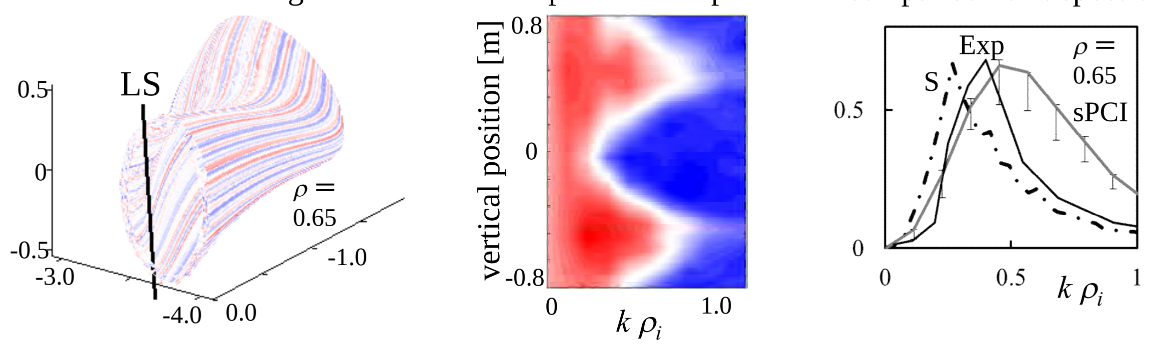
- A. Ishizawa, Y. Kishimoto, and H. Sugama,
  Parity in Torus Plasmas : 5. *Summary and Discussion*,
  J. Plasma Fusion Res. 92, 564 (2016)

Numerical diagnostics has been performed to capture turbulence properties in helical plasmas

Collaborate with Kyushu Univ.

- Combination of simulations for turbulence and experimental measurement gives synthetic diagnostic of fluctuation patterns in helical plasmas.
- Time series of 3-D turbulence data are obtained by Gyrokinetic code GKV, and density spectra are extracted from them by utilizing simulation of phase contrast imaging in the LHD configuration.

measurement configuration | vertical profile of k spectrum | comparison of k spectrum

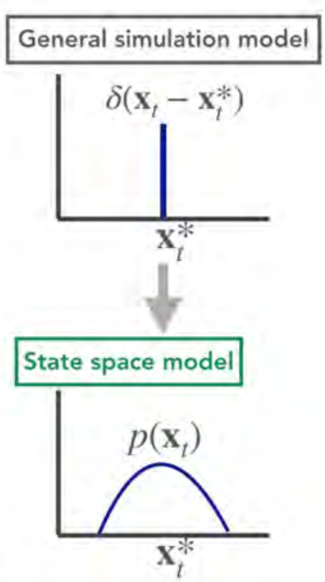


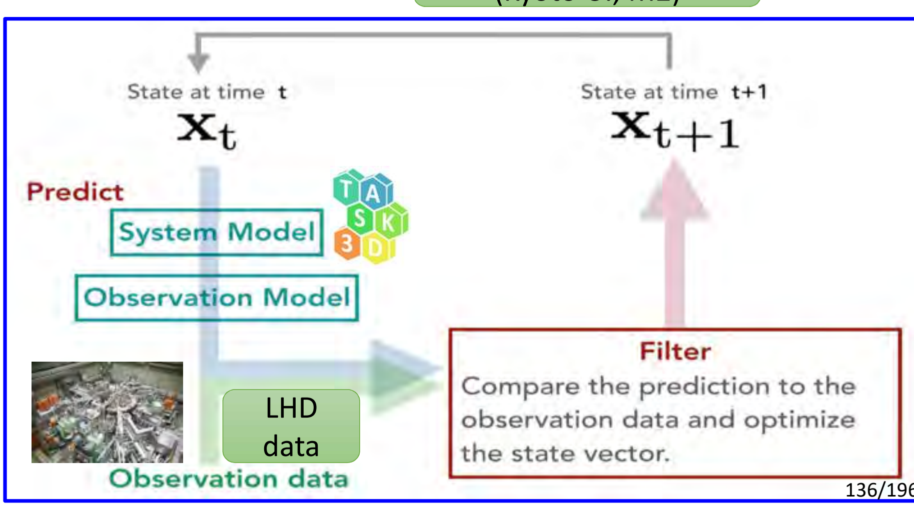
- A signal integrated along the line of sight of the experimental observation of phase contrast imaging is calculated.
- A vertical profile of the density fluctuation spectrum is reconstructed, and the spectrum is compared with the experiment.

Implementation of *Data Assimilation* approach (TASK3D)

- **Data assimilation**: Optimizing a numerical model with observations (by replacing variables, constants and initial values of the model with probability distributions (state space model)
- Successfully employed in **weather/oceanic** area ⇒ **implementation to TASK3D for fusion research** (collaboration established among **Kyoto U., The Institute of Statistical Mathematics (ISM) and NIFS)**

Courtesy of Y. Morishita (Kyoto U., M2)





[3]-(2)

3. Promotion of cooperation and collaborations

(2) Does the NSRP contribute to enhancing functions of universities and institutes as the center of excellence for fusion plasma simulation? Does the NSRP commit to the promotion of interdisciplinary collaboration and research?

- The NSRP coordinates many collaborations with universities and institutes as a COE to enhance their functions for conducting researches based on fusion plasma simulation.
  (Enhancement of functions for education → Chap.[4])
- The NSRP commits to the promotion of interdisciplinary collaboration by organizing workshops and symposia under NINS cooperation programs.

NSRP organizes several workshops for collaboration every year.

List of workshops

- **2016 8 Workshops** (Non-linear problem and visualization, , Plasma-wall Interaction, Peripherical plasma, High-beta plasma, Fluid dynamics, MHD, Visualization)
- **2017 7 Workshops** (Non-linear problem and visualization, , Plasma-wall Interaction, Peripherical plasma, High-beta plasma, Fluid dynamics, MHD, Visualization)
- **2018 9 Workshops** (Non-linear problem and visualization, , Plasma-wall Interaction, Peripherical plasma, High-beta plasma, Numerical simulation, MHD, AI, Visualization)
- **2019 8 Workshops** (Non-linear problem and visualization, , Plasma-wall Interaction, DNA, Deep learning, Peripherical plasma, High-beta plasma, Data mining, Visualization)

A) NSRP plays a central role in collaboration with universities and institutes

- Kyoto University:
  - Electromagnetic gyrokinetic simulation of turbulent transport in helical systems.
  - Divertor plasma modeling of Heliotron J
- Kushu Inst. Tech., Kyoto Inst. Tech., NIMS, RIKEN, Doshisha Univ., Univ. Toyama., IMS :
  - Molecular dynamics study on DNA damage by tritium disintegration.
- Keio University:
  - Tungsten transport and redeposition in LHD
- Nagoya University, QST, Keio University:
  - Divertor footprint in JT-60SA with RMP field
- Nagoya University, Aichi Inst. Tech.:
  - Plasma modeling of NAGDIS-II
- Tokyo Institute of Technology and Okayama Institute of Technology
  - Extended MHD (XMHD) simulations of ballooning modes in LHD
- Kyoto Institute of Technology:
  - MIPS simulation reproduced the experimentally-observed helical structure in RFP
- University of Hyogo, Kobe University, Konan University, Kyoto University, Nagoya University, JAMSTEC, National Defense Academy, Osaka Prefecture University:
  - Visualization of LHD periphery devices, GKV simulation results, magnetic field lines and cosmology simulation of Einstein equation
  - In-situ visualization
- NAOJ:
  - PIC simulations of relativistic jet launched by black holes

Collaborations on EMC3-EIRENE: 3. Plasma modeling of NAGDIS-II 4. Divertor plasma modeling of Heliotron J

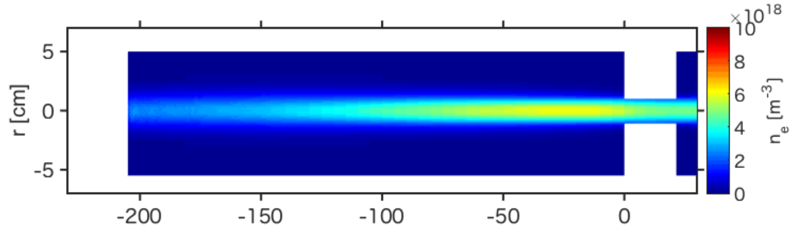
Collaborate with 3) Nagoya Univ., Aichi Inst. Tech., 4) Kyoto Univ.

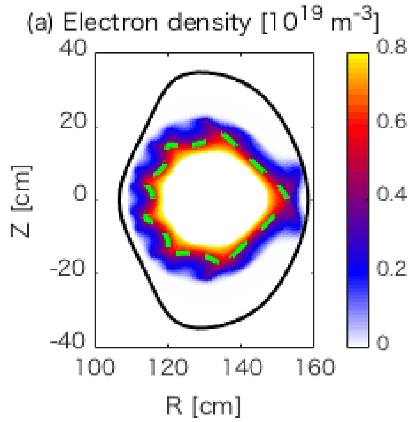
3. Plasma modeling of linear device NAGDIS-II was performed for the first time.

- Plasma was modeled in 3D realistic device and target shape, and energy transport between the plasma and the neutral gas was investigate.

4. Divertor plasma modeling of Heliotron J was performed for the first time.

- Plasm distributions with three different magnetic field configuration were obtained, and heat flux depositions on the wall were investigated.

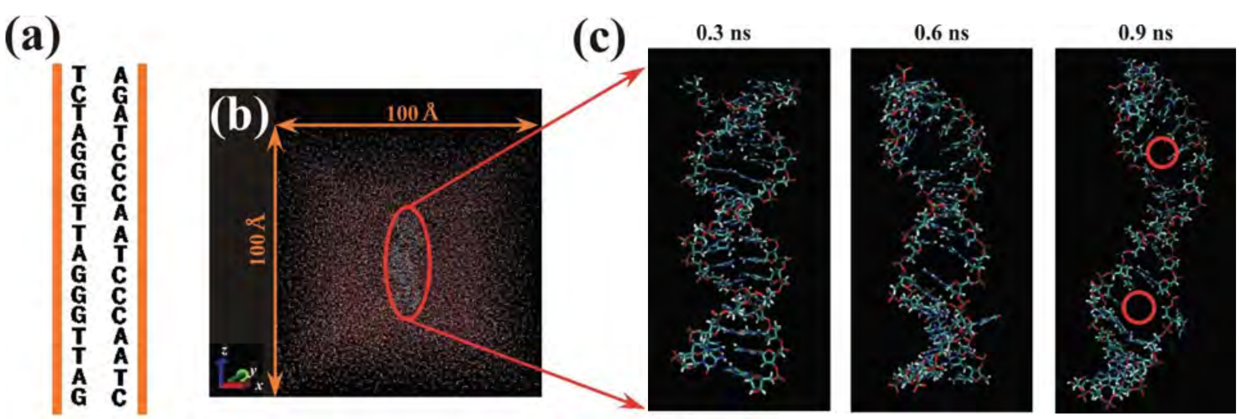




Molecular dynamics study on DNA damage by tritium disintegration

Collaborate with Kushu Inst. Tech., Kyoto Inst. Tech., NIMS, RIKEN, Doshisha Univ., Univ. Toyama., IMS.

- Using molecular dynamics (MD) simulation, we simulate the structural change of a telomeric DNA by β decay of substituted tritium to helium-3.



H. Nakamura, et al., Jpn J. Appl. Phys., (2019) (accepted).

- From the MD simulation, it is found that as the intensity of the β-decays becomes larger or as the temperature is increased, the DNA structure becomes more fragile.

Collaboration with University of Tokyo & Okayama Institute of Technology on LES for XMHD turbulence

- With an intention to apply for extended MHD (XMHD) simulations of ballooning modes in LHD, SGS model has been developed based on DNS of Hall MHD turbulence both for isotropic turbulence and for homogeneous, non-isotropic (magnetized) turbulence.

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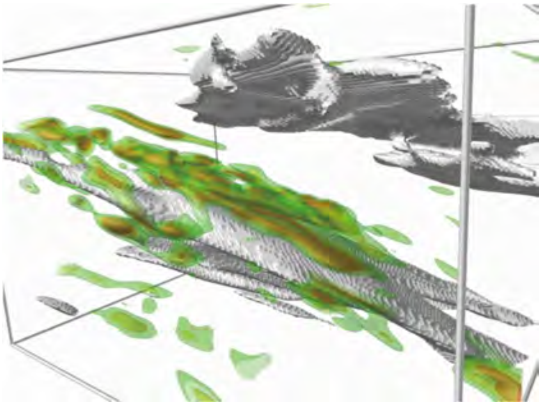
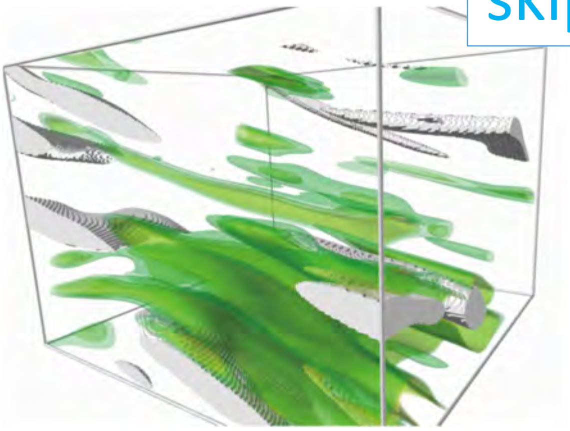


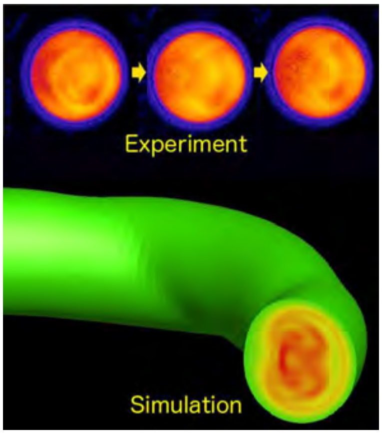


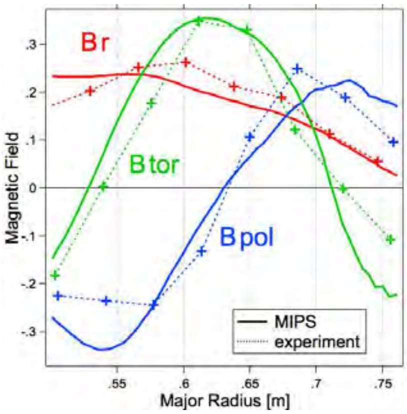
- Our SGS model, which contains effects of flow shear and current density in the grid scale, and reproduce basic nature of Hall MHD turbulence well both for isotropic and magnetized turbulence.

MIPS simulation reproduced the experimentally-observed helical structure in RFP

Collaborate with Kyoto Inst. Tech.

- The initial MHD equilibria for the MIPS nonlinear simulation are calculated by the RELAXFit code with experimental parameters.
- Full toroidal simulations for multiple m=1 modes are carried out for the resistive time scale.



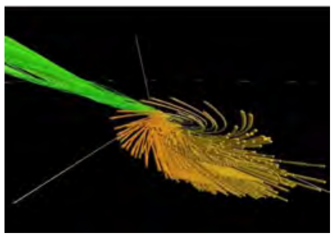


- External kink eigenmode corresponds to magnetic perturbations observed in RELAX device.
- Nonlinear restructure of pressure via magnetic reconnection forms characteristic hollow profile in agreement with the experiment.

Collaboration on visualization methods with University of Hyogo, Kobe University, Konan University, Kyoto University, Nagoya University, JAMSTEC, National Defense Academy, Osaka Prefecture University.

- A game development engine, ex. Unity, has potential as a common development environment of visualization software because it deals with various visualization devices, such as head mount display, smartphone, CAVE and so on. We research the utilization of Unity for scientific visualization.
- In-situ visualization library VISMO is developed to perform visualization process together with simulation on the same supercomputer.
- We visualized the orbit data by solving the Einstein equation in uniform and anisotropic universe model.



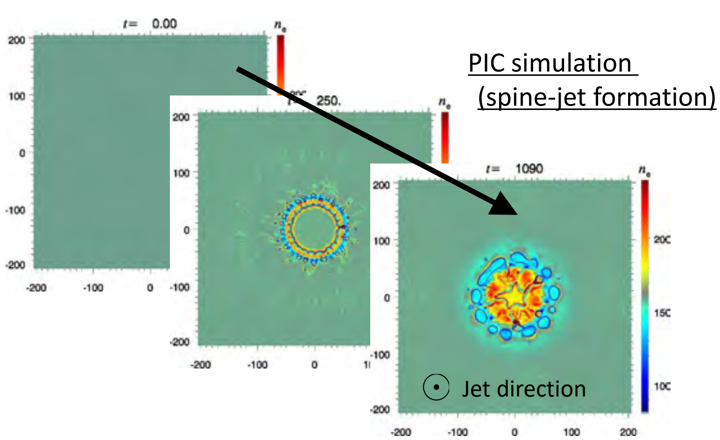



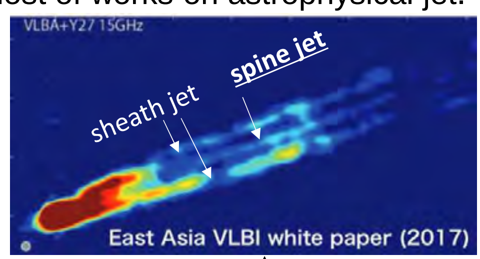
- The CAD data of the periphery devices of LHD can be easily installed to the VR visualization content "LHD vessel".
- The point cloud data is visualized by CompleXcope.
- It was found that each orbit rotated spirally in 3d space.

skip

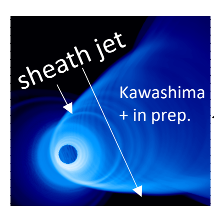
NINS program of Promoting Research by Networking among Institute "Hierarchy and Holism in Natural Sciences" performs PIC simulations of relativistic jet launched by black holes

- Global structure of relativistic jet launched by black holes is calculated by PIC code without using MHD approximation assumed in most of works on astrophysical jet.





Observation
(Spine-sheath jets are found.)



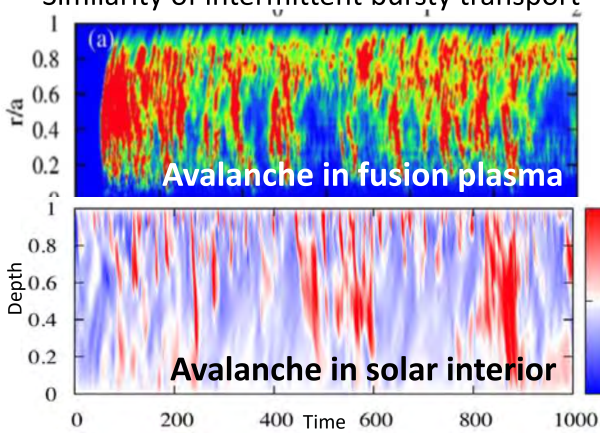
MHD simulation
(Recently, sheath jets are successfully reproduced.)

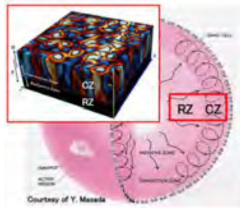
- Mushroom instability (MI), which is a transverse electron-scale instability in relativistic shear flow, induces intermittent magnetic reconnections (MRs) in the jets.
- MI itself and MI-driven-MRs lead to the convergence of electrons toward the jet center with particle accelerations, which can explain the spine-jet structure observed in M87.

NINS cross-disciplinary study on Turbulence, Transport, and Heating Dynamics in Laboratory & Solar/Astrophysical Plasmas: SoLaBo-X (2019~)

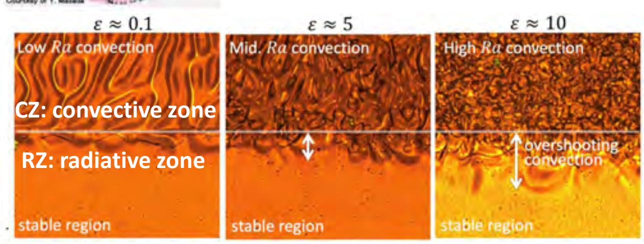
- In NINS program of cross-disciplinary study for young researchers, collaborations among NIFS, NAOJ, and the other Universities are accelerated.
  SoLaBo-X project (Solar + LaBoratory + Cross-disciplinary)
- Utilizing the advantage of high-resolution observations/simulations in laboratory- and solar-plasma researches, the turbulence-related transport and heating dynamics are explored through the mutual exchange of knowledge & scheme.

Similarity of intermittent bursty transport





Visualization experiments for solar turbulent convections:
→ comparison with simulations
→ application to Deep Learning

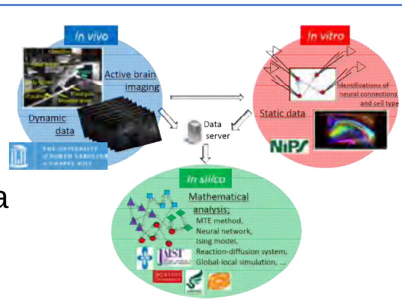


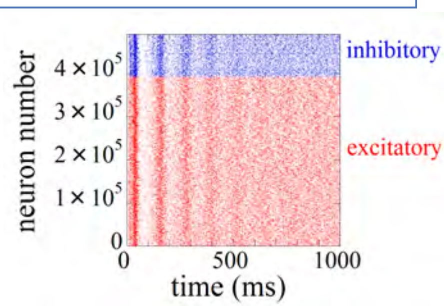
----> Reynolds number

Nakata et al (NIFS), Katsukawa et al (NAOJ), + the other Univ.

NINS program for cross-disciplinary study "Investigation of the laws on the relation between a spatiotemporal neuronal activity and connections of local neural circuits in an active brain" contributes to establishing the novel methodologies for investigation into global dynamics on a cerebral cortex.

- Novel experimental and mathematical methodologies for investigation into global dynamics on a cerebral cortex have been established.





- As a topic in this program, the large-scale simulations of neural circuits which include 1M neurons have been performed in order to develop the huge-scale simulation model of global dynamics on a cerebral cortex with the macro-micro interlocked (MMI) algorithm.

7 collaborators from 2 domestic universities, 2 foreign universities (USA), and 3 institutes (NIPS, IMS, and NIFS).

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PWI simulation is applied into semi-conductor processing as industry-university joint research

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- Multi-scale and hybrid simulation approaches for Plasma-Wall Interaction (PWI) can be applied into the other plasma-material interaction phenomena.
- Beginning 2018, industry-university joint research on semiconductor processing began with the Toshiba Memory Corporation (currently Kioxia).

- The contents are technical provisions related to simulation methods.
- The first result is as follows:

  T. YAGISAWA, S. KATO, A. TAKAYAMA, and A. M. ITO,
  "First Principle Molecular Dynamics of fluorocarbon molecule injection into Si surfaces",
  The 40th International Symposium on Dry Process (DPS2018)
  Nagoya, Japan, November 13-15, 2018.

In addition, under the support program of NINS for cross-disciplinary study, the application of PWI simulation has been currently expanded into astronomy, biology, and so on.

[3]-(3)

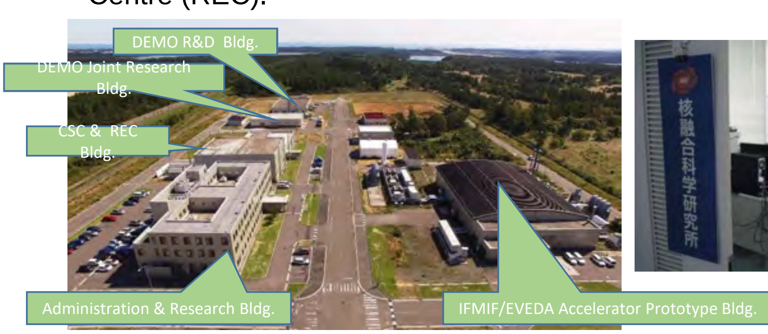
3. Promotion of cooperation and collaborations

(3) Does the NSRP contribute to international cooperation including ITER, BA activities, and others through international collaboration activities?

- Director of the NIFS Rokkasho Research Center is serving concurrently as IFERC Project Leader.
- NSRP members are undertaking collaborative research projects for JT-60SA.
- NSRP members are participating in the ITER/BA activities.
- NSRP contributes to international collaborations with US, EU, China, and Korea.

Cooperation with ITER and BA activities
Activities at the NIFS Rokkasho Research Centre

- At Rokkasho village in Aomori prefecture, International Fusion Energy Research Centre (IFERC) project is implemented as well as IFMIF/EVEDA in the framework of BA activities, in order to contribute to ITER and to the early realization of DEMO.
- The IFERC project is promoting 3 sub projects; DEMO Design and R&D Coordination Centre, Computational Simulation Centre (CSC), and ITER Remote Experimentation Centre (REC).



NIFS Rokkasho Research Center inside of JAEA Aomori Res. & Dev. Centre.

- The roles of the NIFS **Rokkasho Research Centre** (RRC) are to support the cooperation between NIFS/universities and BA activities, and to prepare the environment for promoting a variety of collaborative researches between NIFS/universities and BA activities.
- For such purposes, the head of the RRC is undertaking work as the IFERC project leader from 2010/9 and the RRC has been moved into JAEA Aomori Research and Development Centre on 2012/4.

Director of NIFS Rokkasho Research Center is serving concurrently as IFERC Project Leader (PL)

skip

Tasks of PL

- To coordinate activities of EU and JA Implementing Agencies (IAs).
- To prepare input documents of IFERC Project Committee (PC) for reporting activities and getting recommendation of PC to invite the Steering Committee (SC) to approve proposals. (In spring PC and SC, the main input documents are the annual report of the last calendar year and updated project plan. In autumn PC and SC, those are work program of the next calendar year and summary report. Update of Value Estimates and Allocation of Contributions of the Parties is proposed just in case.)
- To hold and attend various managerial and technical coordination meetings (TCMs). (ex. Extended Project Team Meeting in almost every two weeks with Fusion for Energy (F4E)).
- To support preparation and implementation of the Procurement Arrangements.

Other recent activities as PL:

- To support the successful closing of IFERC project in BA Phase I at the end of Mar. 2020,
    - To compile the Final Report of Demo Design Activity,
    - To compile the Final Report of REC Activity,
    - To complete and report the accounting of credit values,
- To support the creation of IFERC project plan for BA Phase II from Apr. 2020 to Mar. 2025,
- To disseminate IFERC activity to public via website: https://www.iferc.org

NSRP researchers are contributing to IFERC CSC and collaborative research for JT-60SA and IFERC REC

- NSRP members implemented more than 10 simulation projects every year on IFERC CSC Helios as principal investigators (summarized in the Table).
- NSRP members contribute to the committees for the IFERC CSC.
- NSRP researchers are undertaking collaborative research projects for JT-60SA and IFERC REC.

IFERC CSC Helios (2012-2016)

Cycle	EU-JA allocation (80%)	JA domestic allocation (10%)
4th cycle	10 (Dec. 2014 - Nov. 2015)	6 (Apr. 2015 – Mar. 2016)
5th cycle	8 (Nov. 2015 – Dec. 2016)	4 (Apr. 2016 – Dec. 2016)

IFERC CSC JFRS-1 (June 2018-)

Cycle	Project	General (=10k node hours/project)
FY 2018	10	0
FY 2019	6	1

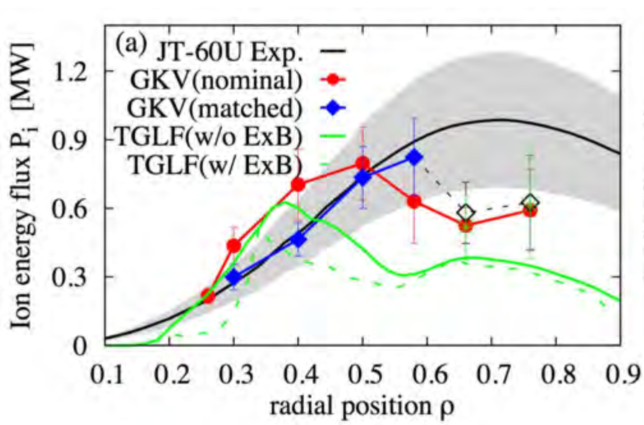
NSRP members are participating in and contributing to ITPA topical groups

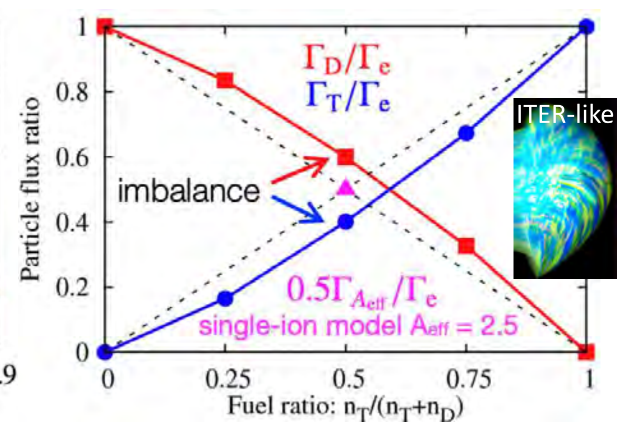
- Three NSRP researchers are the members of ITPA (International Tokamak Physics Activity) topical groups Pedestal and Edge, Energetic Particles, and Integrated Operation Scenarios.
- The number of participants from NSRP for each topical group meeting is summarized in the Table.

Year	Pedestal and Edge	Energetic Particles	MHD	Integrated Operation Scenarios	Transport and Confinement	Total
2013	1	2				3
2014	2					2
2015		2			1	3
2016		2			1	3
2017		1		1		2
2018		1		1		2
2019		4		1		5

Collaborations on GKV: 1. Quantitative validations in JT-60U 2. D-T-He transport in ITER-like plasma

1. Ion and electron turbulent transport was investigated by gyrokinetic simulations based on a realistic JT-60U equilibrium [Nakata+(NF2016)].
- GKV simulations well reproduce the experimental results of the turbulent flux.
2. Multi-ion-species gyrokinetic simulations were carried out to examine the turbulent transport of D, T, and He-ash in ITER-like plasmas [Nakata+(IAEA-FEC2016, IAEA-TM2017)].
- Imbalanced particle transport of D and T is found in 50%-50% mixed plasma.



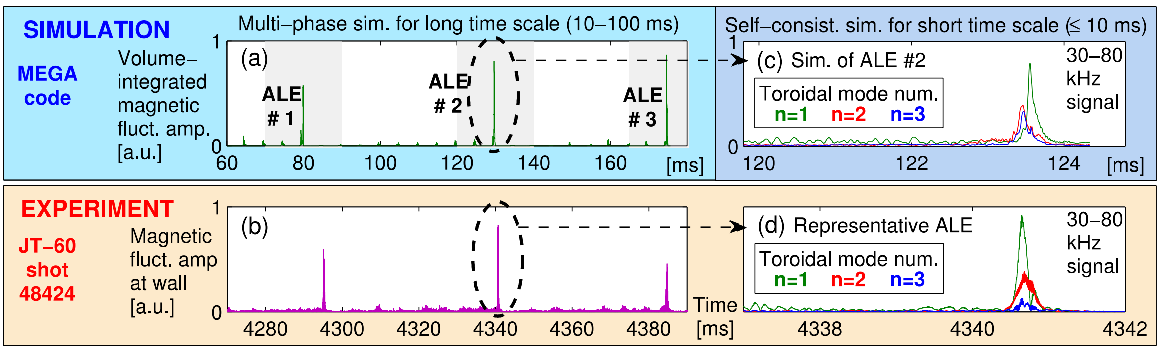


Collaborations on MEGA:
1. Abrupt Large-amplitude Event in JT-60U
2. MHD instabilities in JT-60SA plasmas

1. Abrupt Large-amplitude Events (ALE) observed in JT-60U plasmas were successfully reproduced with the MEGA code [Bierwage+(Nat.Comm.2018)].

- The simulation predicted the excitation of multiple modes at ALE, which was demonstrated by the analysis of the experimental data.

2. Pressure driven and fast-ion driven MHD instabilities were investigated for JT-60SA plasmas during current ramp-up with off-axis NBI [Bierwage+(PPCF2017)].



[Bierwage+(IAEA2016, Nature Comm.2018)]

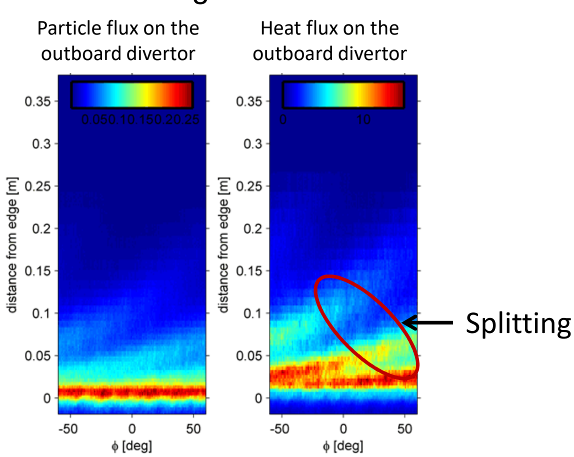
Collaborations on EMC3-EIRENE and MIPS:
1. Divertor footprint in JT-60SA with RMP field
2. ELM mitigation in JT-60SA with RMP field

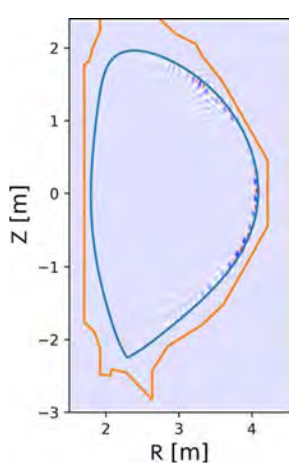
1. Divertor footprint in JT-60SA with RMP field was obtained for the first time by EMC3-EIRENE code.

- Splitting of the flux distribution was obtained corresponding to the toroidal mode number of the RMP field.

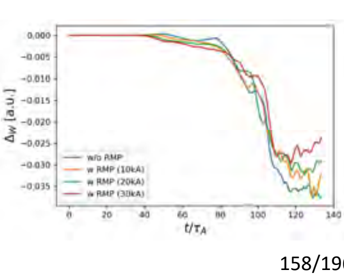
2. The effects of RMP field on the Edge Localized Mode (ELM) in JT-60SA were investigated with MIPS code.

- ELM mitigation with RMP field was demonstrated.





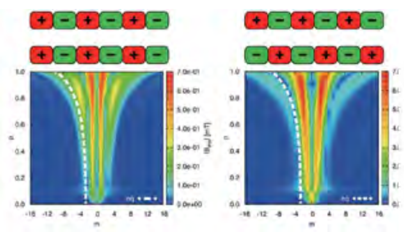
Stored energy loss is mitigated with RMP.



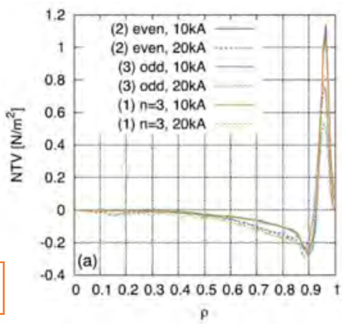
Assessments of RMP and error field effect on plasma rotation in JT-60SA and ITER

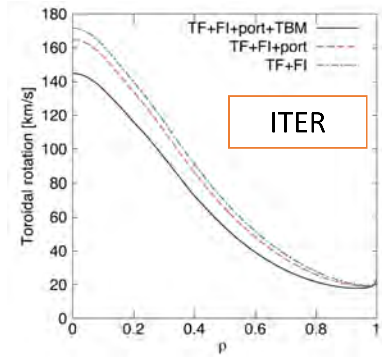
Collaborate with QST

- 3D magnetic perturbation in tokamaks is expected to affect the plasma rotation through neoclassical toroidal viscosity (NTV).
- Neoclassical code FORTEC-3D evaluates NTV in JT-60SA and ITER, and the toroidal rotation profile is calculated by integrated transport code TOPICS.



JT-60SA





- Several patterns of RMP fields in JT-60SA and the NTV in each case are evaluated → study for JT-60SA research plan
- Toroidal rotation profile changes according to the NTVs from error fields caused by toroidal ripples, ferromagnetic inserts, and test blanket modules in ITER.

- The NSRP plays a central role in promoting US-Japan collaboration, wide-ranging collaborations with European institutions, A3 foresight program (Japan, China, Korea), and other international collaborations in fusion plasma simulation

- NSRP plays a major role in collaborations with the United States through Joint Institute for Fusion Theory (JIFT) activities: workshops and exchange of scientists
- NSRP promotes wide-ranging collaborations with European institutions.
- Collaborations with China and Korea are progressing under the A3 foresight program and post-CUP (Core-University-Program).

NSRP conducts collaborations with US through Joint Institute for Fusion Theory (JIFT) activities

- NSRP supports US-Japan workshops and exchange scientists to promote simulation science based on fusion plasma research.
- NSRP contributes to management of JIFT activities as a host Institute.

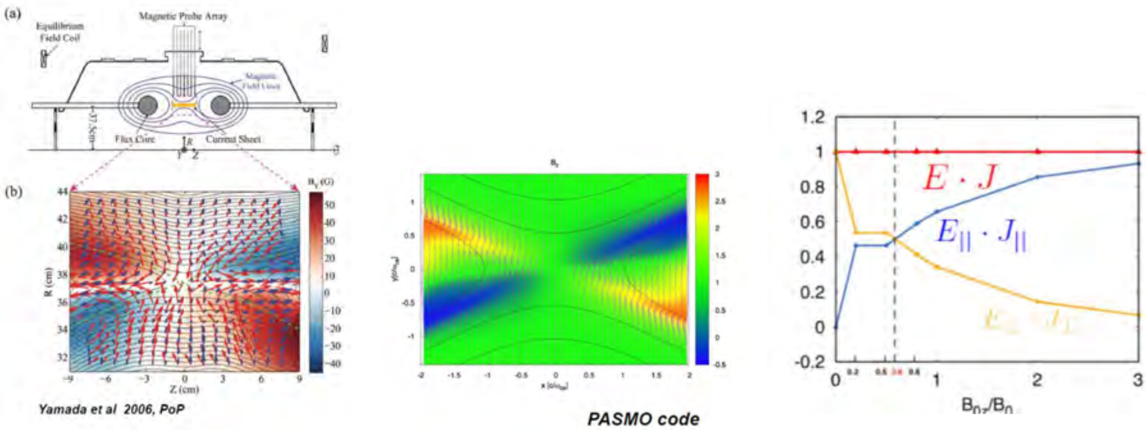
JIFT Steering Committee	
US Members	***Japanese Members***
F. Waelbroeck (IFS)—Co-Chairman A. Arefiev (IFS)—Co-Exec. Secretary D. Spong (ORNL) J. Mandrekas (DOE)	H. Sugama (NIFS)—Co-Chairman S. Ishiguro (NIFS)—Co-Exec. Secretary S. Murakami (Kyoto) Y. Sentoku (Osaka)
JIFT Advisor Committee	
US Members	***Japanese Members***
A. Aydemir (IFS), P. Catto (MIT), B. Carreras (BACV Solutions), V. Chan (GA), B. Cohen (LLNL), W. Horton (IFS), W. Tang (PPPL), and P. Terry (UWM)	Y. Todo (NIFS) Y. Kishimoto (Kyoto), Z. Yoshida (Tokyo) T.-H. Watanabe (Nagoya), M. Yagi (QST)

NSRP actively conducted JIFT workshops and exchange scientists in 2016-2019

Year	Workshops	Exchange visitors	
		From NIFS	To NIFS
2016	**3D Physics** by Y. Suzuki (NIFS) and E.J. Strait (GA) at Kyoto **Extended MHD** by H. Miura (NIFS) and L.E. Sugiyama (MIT) at Kyoto **Exascale Computing** by T.-H.Watanabe (Nagoya) and C.S.Chang (PPPL) at Oak Ridge	Y. Suzuki / PPPL H. Sakagami / Nevada H. Miura / IFS	D. del-Castillo (ORNL) D.A. Spong (ORNL)
2017	**Stellarator/Heliotron** by S. Murakami (Kyoto) and J. Talmadge (Wisconsin) at Kyoto **Multiscale methods** by S. Ishiguro (NIFS) and S. Parker (Colorado) at Boulder **Exascale Computing** by T.-H.Watanabe (Nagoya) and C.S.Chang (PPPL) at Kashiwa	Y. Suzuki / PPPL Y. Todo / IFS T. Moritaka / PPPL & IFS	I. Dodin (PPPL) J. Varela (ORNL) D. Hatch (IFS) K. McCollam (Wisconsin)
2018	**Multiscale methods** by S. Ishiguro (NIFS) and S. Parker (Colorado) at Nagoya **Exascale Computing** by T.-H.Watanabe (Nagoya) and C.S.Chang (PPPL) at PPPL	H. Miura / IFS	D. Spong (ORNL) M. Cole (PPPL) W. Wang (PPPL) A. Bader (Wisconsin)
2019	**Stellarator/Heliotron** by S.Murakami (Kyoto) and D.Anderson (Wisconsin) at Madison **Exascale Computing** by M.Nunami (Nagoya) and C.S.Chang (PPPL) at Kobe	H. Sakagami / Nevada T. Moritaka / PPPL	D.A. Spong (ORNL) B. Breizman (IFS) L. Zheng (IFS) L.E. Sugiyama (MIT)

Collaboration with PPPL and Princeton Univ. has promoted magnetic reconnection studies.

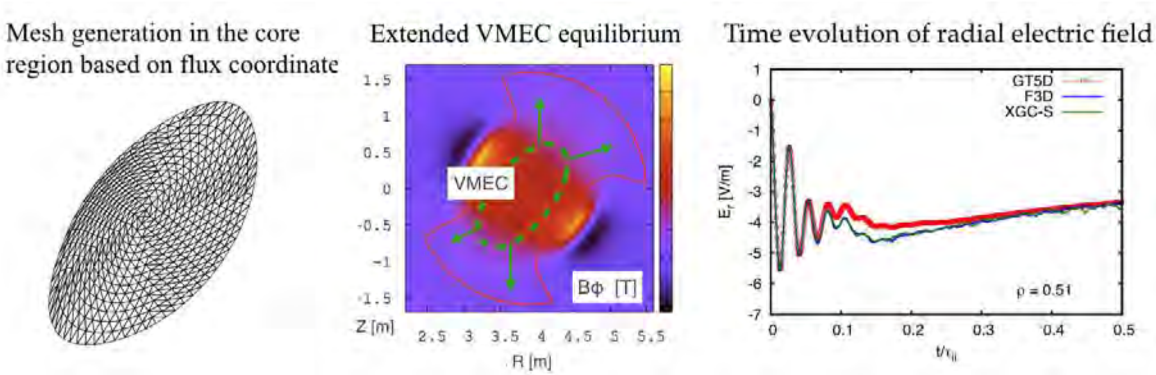
- NINS-Princeton collaboration has promoted studies of magnetic reconnection in laboratory plasmas and the Earth magnetosphere.



- PIC simulations have reproduced the experimental data from MRX and observed results in the magnetosphere by MMS satellites .
- We have found the energy partition between fields and different particle species and a mechanism for electron heating in high guide field.

Development of Global Gyrokinetic Code toward Core-Edge Coupling Simulation of Helical Fusion Devices

- We are developing a global gyrokinetic code, XGC-S, using particle-in-cell and finite element methods for core - edge coupling simulations of Helical fusion devices in collaboration with PPPL.
- We employ extended 3D-VMEC equilibria and field-following triangular meshes that cover the entire region inside the vacuum vessel.



- Basic benchmark tests on neoclassical transport, linear ITG and high-energy particle confinement have been performed.
- Results are consistent with those obtained by using other simulation codes in NIFS, i.e., FORTEC-3D, GT5D and HINT2.

Core formation of asymmetrically driven cone-guided targets have been simulated by IMPACT-3D code

- An Energy absorption profile for one laser beam is calculated by the ray-tracing code, and it is interpreted as a pressure perturbation profile.
- The pressure perturbation profile is duplicated and overlapped on the sphere surface as initial conditions, and fully 3D hydrodynamic simulations are performed by using IMPACT-3D code.

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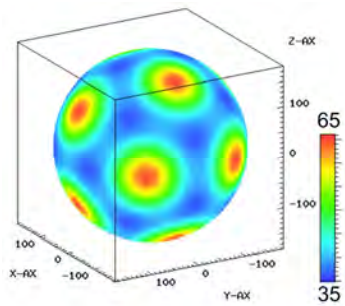
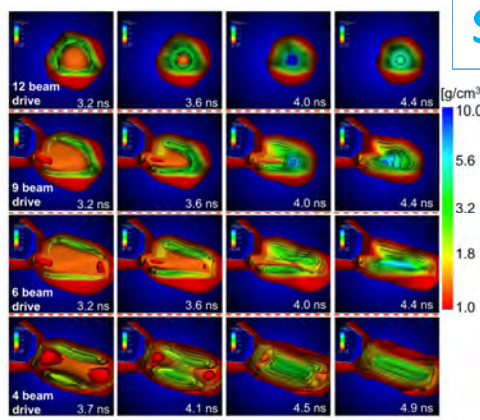
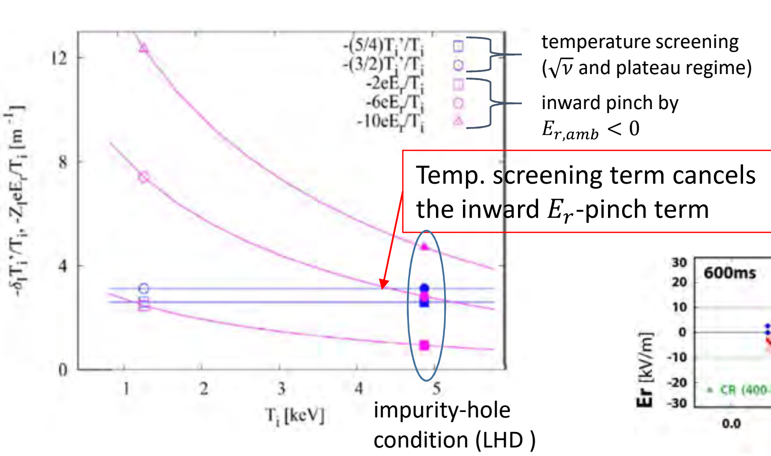


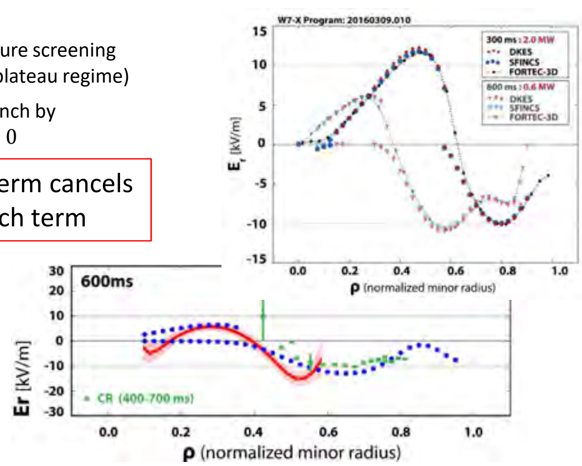


- Core formations for 12 laser beams without the cone and 9, 6 or 4 laser beams with the cone are investigated.
- The maximum density and areal density are measured for each case, and implosion degradations due to asymmetry are evaluated.

NSRP collaborations with EU on the neoclassical transport analysis in stellarator / heliotron

- Neoclassical transport theory / simulation collaborative researches on LHD, W7-X, TJ-II ,etc. have been carried out.





- Possibility of moderation of impurity accumulation in high-T_i, negative-E_r plasma is shown by neoclassical transport theory (left). [Velasco et al, Nucl. Fusion 2016]
- Confirmation of ambipolar-E_r measurements (XICS and CR) with three NC simulation codes in W7-X high-T_e discharge (right) → validation for "neoclassical optimized" design concept. [Pablant et al, Phys. Plasmas 2018]

Collaborations in kinetic simulation studies with Europe

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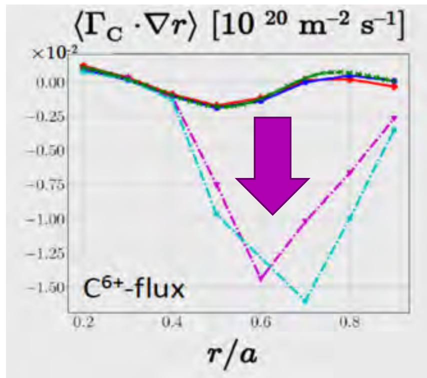
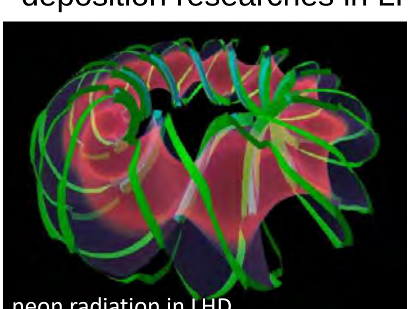
- Neoclassical simulation studies for impurity particle transport in LHD impurity hole plasma, and modeling studies of turbulent transport in stellarators were performed under the collaboration with IPP Greifswald and Eindhoven University of Technology.

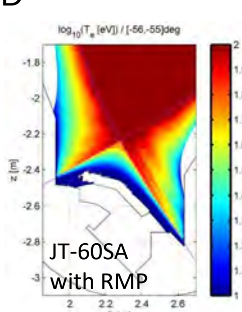


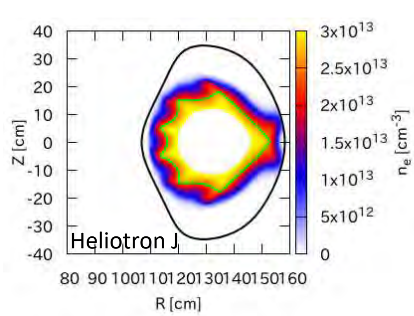
- Flux-surface potential variations $\Phi_1(\theta,\zeta) = \Phi - \langle\Phi\rangle$ cause more inward Γ_c which is observed in local NC transport simulations.
- This means that more precise physics should be considered to explain the impurity hole generation in terms of neoclassical transport.

Collaborations with Max-Planck IPP and FZ Jülich have promoted many researches on divertor modeling

- EMC3-EIRENE code developed in Max-Planck have been applied to
  - plasma-neutral interaction study with different divertor geometry in LHD
  - impurity transport modeling with gas puff in LHD
  - dust particle transport in LHD
  - JT-60SA divertor modeling with RMP
  - Heliotron J divertor modeling
  - and many other works
- Impurity transport and plasma-wall-interaction code ERO2.0 developed in FZJ has been introduced to LHD this year and will be applied to impurity deposition researches in LHD

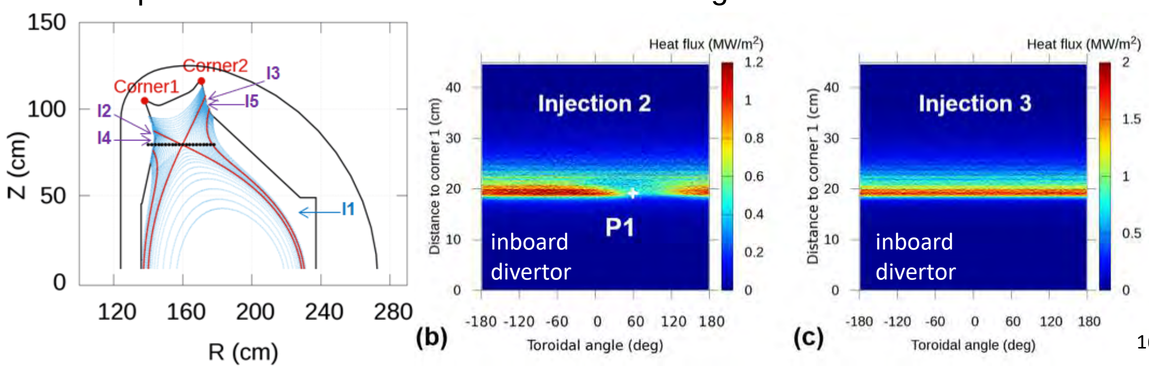






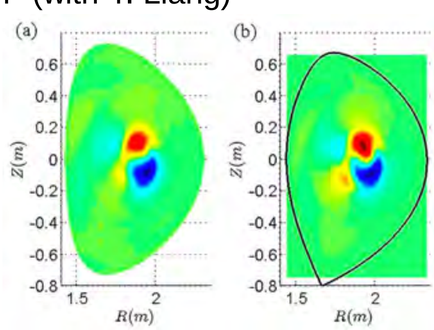
Collaboration with Dalian University of Technology has revealed toroidal asymmetry effect of neon puff

- Impurity transport study of EAST SOL/divertor plasma has been performed by using EMC3-EIRENE code.
- Neon puff at "I2" and "I3" near the strike point on the divertor causes toroidally asymmetry heat flux reduction on the divertor of the same side as the puff because of localized neon transport.
- On the other hand, the puff causes symmetry and weak reduction on the opposite side divertor plate because of global neon transport from the one side to the other side.
- This result suggests possibility of strong heat load reduction with multiple neon puff distributed over the entire toroidal region.



Collaborations with China and Korea in A3 Foresight Program and Post-CUP

- ASIPP
  - Energetic particle driven instabilities in EAST tokamak (collaborating with Y. J. Hu, Y. B. Pei, and N. Xiang)
  - Divertor plasma modeling (with G. J. Niu, Q. Xu, Z. S. Yang, G. N. Luo)
  - Plasma response modeling for magnetic field structure induced by RMP (with Y. Liang)



Comparison of spatial profile for an Alfvén eigenmode in EAST tokamak between (a) M3D-K and (b) MEGA.

[Hu+(PoP2016), Pei+(PoP2017), Pei+(PoP2018)]

- DLUT (Dalian University of Technology)
  - Effects of energetic electrons on Alfvén eigenmodes with MEGA (with J. L. Wang, Z. X. Wang)
  - Divertor plasma modeling with EMC3-EIRENE (with S. Dai)

[4]

4. **Human resources development**

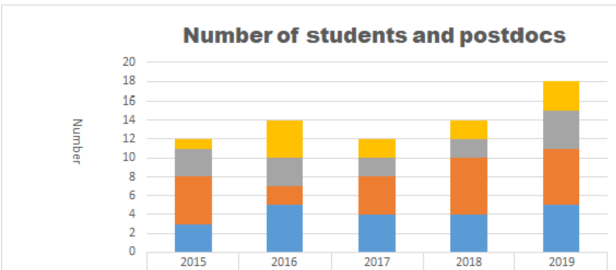
Does the NSRP contribute to the development of human resources required for maintaining high-level simulation research activities toward the future?

The NSRP contributes to the development of human resources required for maintaining high-level simulation research activities toward the future:

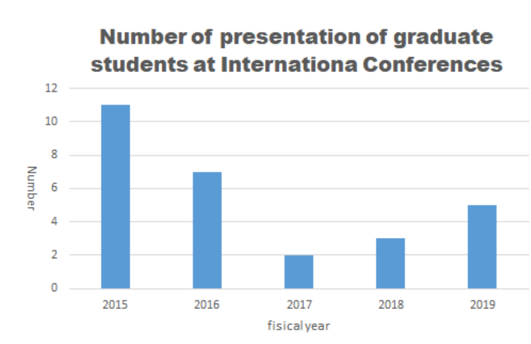
(1) Education programs of Sokendai and of the other graduate schools at Nagoya, Nagoya Inst. Tech., etc.
(2) Cooperation programs with high schools in science education (Super Science High School program)
(3) Sokendai Summer School
(4) Sokendai Asian Winter School on Simulation Science

NSRP contributes to the development of human resources through education of graduate students

- NSRP supports simulation research of graduate students (from Sokendai, Nagoya Univ., Nagoya Inst. Tech., etc.).



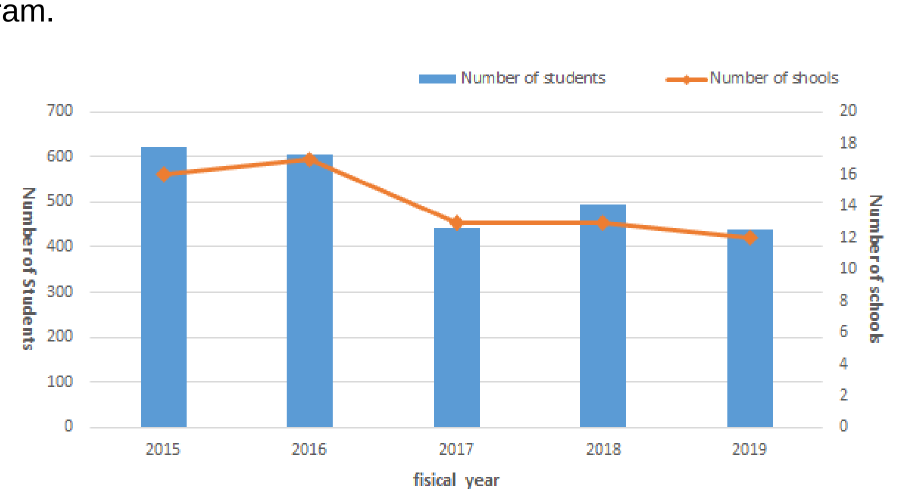
	2015	2016	2017	2018	2019
Posdocs	1	4	2	2	3
Other Univs.	3	3	2	2	4
Cooperative Univs.	5	2	4	6	6
SOKENDAI	3	5	4	4	5



- Graduate students made 28 presentations at international conferences in 2015-2019.
- Graduate students and postdocs published 27 and 10 papers, respectively, as first authors in refereed journals during 2016-2019.

Cooperation with high schools in science education, SSH, has been promoted in collaboration with NSRP

- Cooperation programs with high schools in science education have been promoted at NIFS with the help of the "**Super Science High School" (SSH)** program.



- More than 400 students come to NIFS for this program each year.
- The NSRP has contributed to three subjects in the program:

''Numerical Simulation," "Programming and Visualization," and "Virtual Reality"

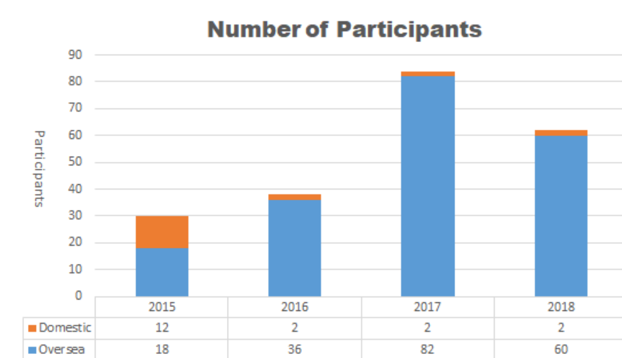
Sokendai Summer School provides graduate students with opportunities to experience the most up-to-date research at NIFS

- The purposes of this School are to gain publicity for fusion science and to look for the students who would like to become researchers in the field.

- The students experience research activities under the guidance of Sokendai teachers and students, and present their activities at the meeting.
- The NSRP staff propose subjects and accept from two to four students in each subject.

“Sokendai Asian Winter school” provides students and young scientists from Asia with an opportunity to study leading-edge fusion science

- The school gives lectures on plasma physics, fusion science, simulation, experiments.
- The school was held in Thailand from 2016.



[5]

5. Future Plan

Is the future research plan suitable for progressing toward the goal of the NSRP? Does it also contribute to establishing the future plan of the National Institute for Fusion Science?

The NSRP plans to further advance the researches for improving, integrating, and validating simulation codes with the upgraded Plasma Simulator toward construction of the Numerical Simulation Reactor which contributes to designing high-performance helical fusion reactor.

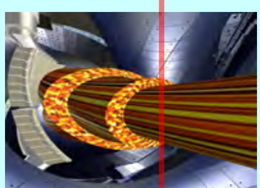
- Each of eight task groups has a roadmap which shows specific tasks to be solved through domestic, international, and inter-project collaborations.
- The NSRP directly contributes to optimized configuration study for the Next Generation System (NGS) in the future plan of NIFS.

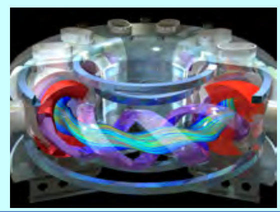
Three-step plan of the NSRP:

1. To develop simulation codes for various physics elements of fusion plasmas
2. To integrate and validate simulation codes for treating multi-scale and multi-physics phenomena
3. To construct a system of codes [=Numerical Simulation Reactor (NSR)] for contributing to designing high-performance helical fusion reactor

Roadmap for realizing Numerical Simulation Reactor (NSR)

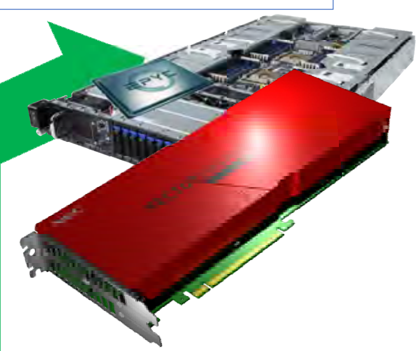
2010 — 2nd mid-term — 2016	3rd mid-term (2019) — 2022	4th mid-term — 2028
Development of simulation codes for various physics elements constituting fusion plasmas	Extension and integration of codes for treating multi-scale and multi-physics phenomena V&V and application of codes by collaboration with experiments and engineering	Further development and completion of NSR for contributing to designing high-performance helical fusion reactor





"Plasma Simulator" is going to be upgraded to a new system: total peak performance more than 10 Petaflops in June 2020

- **Plasma Simulator** is going to be replaced to a new system in June 2020.
- The peak performance of the new PS system is more than four times of the current FX100 system (to be operated until the end of Feb. 2020.)

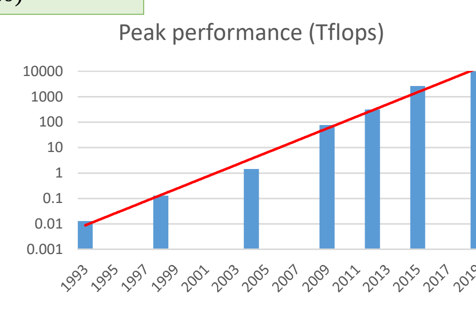


HITACHI SR16000/L2 (peak speed: **77TF** memory: **16TB** period: 2009 – 2012)

HITACHI SR16000/M2 (peak speed: **315TF** memory: **40TB** period: 2012 – 2015)

FUJITSU PRIMEHPC FX100 (peak speed: **~2.6PF** memory: **~81TB** period: 2015-2020)

NEC (model name TBD) (peak speed: **~10.5PF, memory: ~200TB:** period: 2020-2025)



Plasma Fluid Equilibrium Stability Group

Objectives :

- Further development of equilibrium code and application to 3D plasmas
- Identification of key stability physics in LHD and quantitative prediction of stability boundary for next device in NIFS

objective	task	2017-2019	2020 (New PS)	2021	2022	2023-2025	2026-2028
Further development of equilibrium code	Incorporation of flow and anisotropic pressure	Flow incorporation	Incorporation of anisotropic pressure				
		Divertor field line calculation of heliotron & modular systems					
Identification of key stability physics and quantitative prediction of stability boundary for next device	MHD stability of quasi & standard interchange mode	Analysis of global flow effects	Diagram of standard & quasi interchange modes		Landau damping effects		Effects of global flow and islands
	Next generation device design	D shape effects	Optimization of helical, poloidal, and modular coils		Combining neoclassical transport	Combining turbulence transport	
Extension of MHD models and comprehensive understanding of toroidal plasmas	Incorporation of kinetic ions & plasmoid analysis	Kinetic thermal ion effects on linear stability	Kinetic thermal ion effects for nonlinear evolution		Kinetic thermal ion and energetic ion effects		
		Pellet injection in LHD plasma with an island			Analysis of pellet plasmoid in LHD		
	LES with source and sink	Concept-proof of LES of XMHD	CITM study by LES of XMHD with new SGS model for microscopic effect		Pressure-driven mode study by new LES model		Full model extension for two-fluid equations

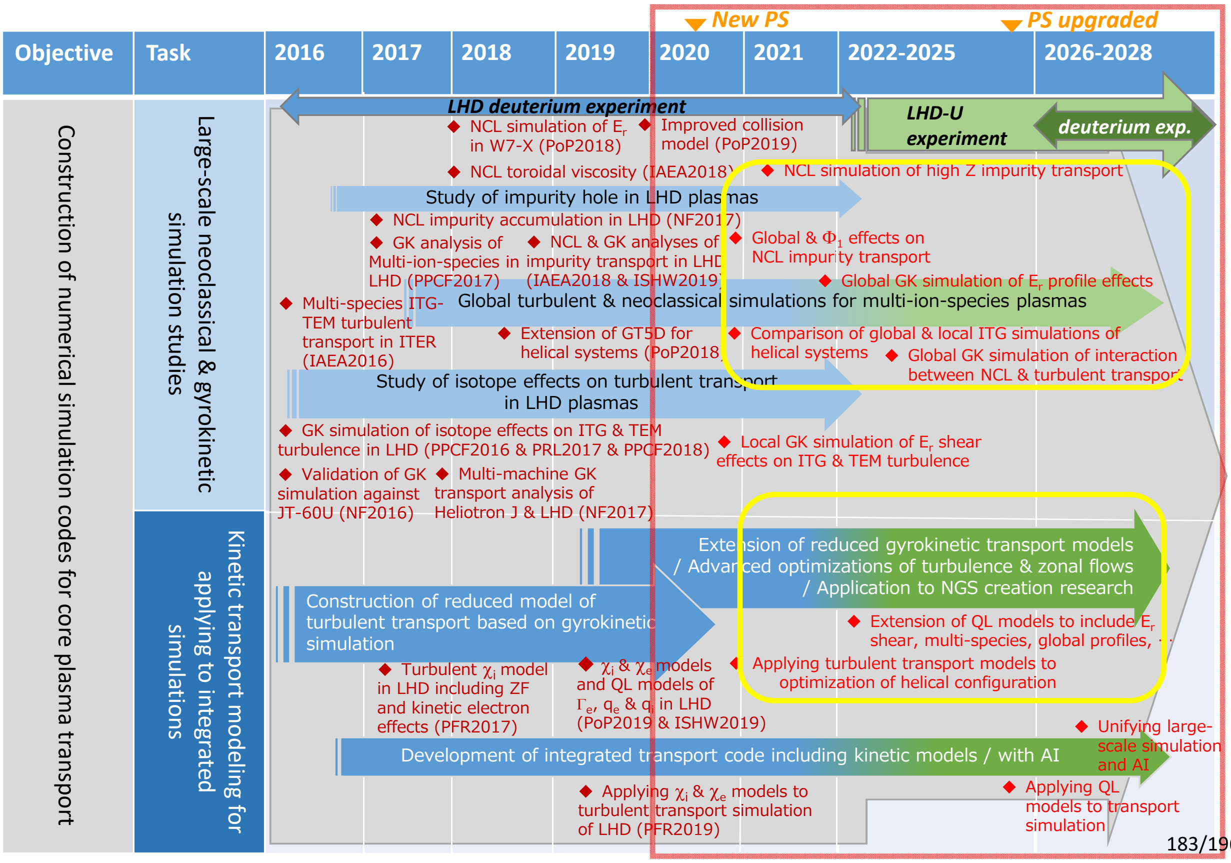
Energetic-Particle Physics Group

Objectives :

- **Validation of MEGA code on LHD and tokamak plasmas.**
- **Improve MEGA code with ICRF and drift waves for predictive simulation of burning plasmas.**
- **Simulations of high-frequency waves and automatic experiment analysis with GNET.**

objective	task	2016	2017	2018	2019	2020-2023 (New PS)	2024-2028 (PS upgraded)
Understanding of EP driven instabilities	Simulation study of AE and GAM	**EP critical distribution/AE burst** (NF, NJP, NF)				**AE with ICRF**	**AE/ITG/ZF**
		EGAM in 3D equilibrium (PRL, NF, NF)				**EP distribution F**	**Higher frequency waves**
				EIC			
		ICE and LHW (PFR, PFR)					
Validation and verification	Comparison with experiment, theory, and other codes	**V&V on LHD experiment** (PoP)		**V&V on LHD deuterium experiment** (NF, NF)			
						V&V on CFQS	
		V&V on tokamaks (NF, NF, CPC, NF, NatureComm., NF)			**V&V on JET DT**	**V&V on JT-60SA**	
Code development	Development of MEGA and/or kinetic codes	**Kinetic effects of bulk plasma and energetic electrons** (NF, PPCF)				**ICRF fast ions**	**Reduced EP transport model**
						MHD with drift waves	
		NBI in time-evolving plasma (GNET) (NF)			**Automatic exp. analysis (GNET)**		

Neoclassical & Turbulent Transport Simulation Group



Peripheral Plasma Transport Group

Objectives :

- Three-dimensional transport analysis of edge plasma in LHD [2,4]
- Modeling study on edge plasma physics, core/edge coupling, and plasma-wall interaction [1,3]

objective	Task	2017-2019	2020 (New PS)	2021	2022	2022-2025	2026-2028
Transport analysis of particle and energy	Validation with experiment; Development of 3D edge transport code	Impurity seeded plasma modeling and validation with LHD experiment (→ 2021, dashed → 2028)					
			Detach modeling of NAGDIS-II (→ 2022)			Hydrogen mol./atomic proc. (→ 2028)	
		Erosion/transport/redeposition modeling of LHD (→ 2022, dashed → 2028)					
			Bolometer data analysis, application to experiment	Bolometer data analysis, application to experiment			
Divertor modeling / plasma-wall interaction / dust dynamics	Collaborations with other groups / institutes	Dust transport in LHD		Validation with experiment (→ 2022)			
		JT-60SA modeling with RMP, and toroidal coil modulation		JT-60SA modeling with RMP, and toroidal coil modulation (→ 2022)		Validation with experiment (→ 2028)	
		Heliotron J modeling		Various Heliotron J configurations (→ 2022, dashed → 2028)			
		NAGDIS-II modeling					
		EAST divertor modeling (→ 2021, dashed → 2028)					
Modeling study toward prediction and optimized divertor	Devitor design / Transport model development	Divertor concept study for the next generation device		Particle and energy transport in divertor plasma (→ 2022)		Divertor design study (→ 2028)	
		FFHR divertor					

Plasma-Wall Interaction Group

Objectives :

- Tungsten divertor physics; analysis of tungsten atomic level behavior by plasma irradiation
- Expansion to other materials from tungsten to investigate future plasma facing materials for DEMO reactor.

objective	task	2016—2019	2020-2023	2024-2029
Tungsten divertor physics (Nano structure formation, Hydrogen recycling model)	Fuzz formation	• BCA-MD-KMC multi-hybrid sim.		• toward versatile multi-hybrid (5 pieces or more)
	structure change under irradiation		• On the fly KMC (KMC-MD hybrid)	
	New divertor material		• Z-Universal potential model development (MD & DFT)	
	Hydrogen Recycling model	• Construction of Prototype MD model (graphite+hydrogen)	• Construction of MD model (tungsten+hydrogen) • Data collections by MD	• hydrogen isotopes • Other materials (SUS, beryllium etc)
plasma application	Industry-university joint research	• with Toshiba Memory Corporation *The details is non-disclosed for the contrast with TMC. *Schedule is not decided yet, depending to TMC.		
Effects of Radioactive material	Tritium disintegration effect of biopolymers	・First MD modeling of DNA disintegration by tritium (Guanine of telomere structure)	・Expanding to other bases of DNA	・Expanding to other DNA or Proteins

Integrated Transport Code Group

Objectives :

- **Further development and application (validation) of the integrated transport analysis suite, TASK3D-a [2]**
- **Facilitating the development of predictive version, TASK3D(-p), and its programmatic application for steady-state higher-performance LHD plasmas and FFHR design study [2,4]**

LHD (deuterium) experiment

objective	task	2016	2017	2018	2019	2020-2023	2024-2028
Analysis suite, TASK3D-a	Further extension of physics modules and applications (validation) against LHD (deuterium) experiment	**a02-> a03, a04** • Extension of NBI modules (to be compatible to LHD deuterium experiment) • Loose coupling to large-scale simulation codes (FORTEC-3D, PENTA, SFINCS, and GKV-X) for their smoother applications to and benchmarking activities with LHD plasmas • Easy-to-use neutron emission rate calculation tool established • TASK3D-a has been basis for studying energetic particles behaviour in LHD deuterium plasmas (extensive application for systematic analyses, TASK/FP,				• Further contribution for investigating isotope effect and energetic particles behaviour (database creation for LHD deuterium experiment) • Further integration (ex., core-edge coupling, impurities, enhancing collaborations with other groups in NSRP) • Strengthening activities related to burning plasma issues (towards **Numerical Simulation Reactor, NSR**)	
Common modules		*Increasing relevance (H/He comparison, isotope study)*				*Validations against LHD plasmas* *Implementation of steady-state issues*	
Predictive suite, TASK3D(-p)	Prediction toward steady-state high-performance LHD and FFHR	• Deduction of relevant transport model(s) utilizing LHD plasmas : Gyro-Bohm, Gyro-Bohm x ∇T, Zeff, Aeff (for deuterium plasmas) • Consolidation of GNET and GNET-TD for more accurate NBI heating analyses • Link to "**data-driven Science**" • **Data Assimilation** (Kyoto U. – The Institute of Statistical Mathematics (ISM) – NIFS) • Collaboration with **Fusion Engineering Research Project (FERP)** : implementation of TASK3D-a modules for energy-balance analysis, start-up scenario → Basis for NHTR				• Comparison among several transport models to induce the relevant model, and full implementation of **data assimilation** (all towards NHTR) • FFHR-d1 start-up to whole-duration simulation (as a prototype NHTR) • Plasma control scenario development (possibly with **data-driven** community)	• Demonstration of **data assimilation** for steady-state operation.

Provisional version, evolution of NSR

Multi-hierarchy physics group

Objectives :

- Whole-volume modeling including core and edge regions of helical fusion devices
- Renormalization of microscopic and kinetic processes to XMHD by employing SGS model for LES.
- Clarifying physics in primitive processes, which supports the above models, by using PIC simulations.

Objective	Task	2015-2019	2020 *New PS*	2021	2022	2023	2024-2028 *PS upgrade*
Core-edge coupling	Gyrokinetic-PIC	Basic global gyrokinetic simulation in helical core region	Development of gyrokinetic field solver for stochastic region Verification of edge simulation		Neoclassical / electrostatic turbulent simulation in helical edge region		Core-edge coupling phenomena with impurity transport and transport barriers
Multi-hierarchy	Extended MHD (XMHD)	Concept-proof of LES of XMHD model (MUTSU/MINOS)	・Parameter-renormalization for primitive processes for XMHD-LES (MUTSU/MINOS) ・Development of full two-fluid code for study of LES		・XMHD-LES /full two-fluid LES SGS model optimization for instability simulations (MUTSU/ MINOS) and basic study of full two-fluid LES		Study of nonlinear evolution of short-wave instability of magnetized plasmas by fully two-fluid LES
			Providing basic data				*Providing basic data*
Clarifying physics in primitive processes	Plasma Heating	Reconnection by 2D PASMO	Reconnection by large-scale 2D PASMO	Reconnection by 3D PASMO	Plasma merging in whole poloidal surface by 2D PIC		Plasma merging with large-scale PIC in a curved geometry
	Boundary Layer	Filament by p3bd / Detachment by PAMCADE	Filament by up3bd / Detachment by PAMCADE including recombination		Radial and parallel transports during detachment state by up3bd-PAMCADE		***Connection of up3bd-PAMCADE to global codes (e.g., XGC-S)***
			Collaboration with Peripheral Plasma Transport Group				

Main achievement 2015-2018:
・Development of SGS model for LES of XMHD (2016) and application for instability study f LHD (NF 2017)

Main achievement 2015-2018:
・Extension of XGC to non-axisymmetric geometries, examination of GAM oscillation and particle loss at the material wall (IAEA-FEC2018)

Main achievement 2015-2018:
・Ion heating mechanism in an ST (IAEA-DEC2018, PoP2019)
・Impurity ion transport by filaments (NF2017, NME2019), Isotope effects (IAEA-FEC2018) and kinetic effects (Plasma 2018, PoP2019) on filaments

Simulation Science Basis Technology Group

Objectives :

- Developing methodologies and techniques of scientific visualization and simulation
- Contribution to the design of FFHR/DEMO reactor

objective	task	2016-2019	2020-2023	2024-2029
VR Visualization (Vis.) Research	Upgrade of VR system	• Upgrade of projectors, Unity and MiddleVR, HMD (2016) • Upgrade of PC cluster (2018) • Upgrade of Linux system (2019)	• Replace of tracking system • Upgrade of PC cluster system	• Upgrade of VR projectors • Upgrade of Linux system
	Sophistication of software	• 3D sound (2016) • Porting of vlhd to HMD (2017) • LHD (2018) • Impurity radiation (2018) • Visualization of magnetic field lines (2019) • GK visualization (2019)	• Virtual measuring probe • Utilization of game development engine • HMD, WebGL • Utilization of machine learning	• Additional integration of simulation, experiment and device data.
	VR vis. of CAD data	• Vis. Animation • Animation of robot systems • Structural analysis Press Release JSST Award NF ITC	• Animation based on mechanism analysis results	• VR visualization of fusion plant
In-situ Visualization		• Development of point cloud • Interface module • CAVE • Visualization of particle • Optimization for FX100 • Functional extension ITC AAPPS-DPP(Invite) ITC	• Implementation of user interface • Functional extension in response to requests	• Functional extension in response to requests
Development of Parallel Programing Language	Development of XMP	• XMP workshop, Omni compiler v1.1.0 (2016) • XMP workshop, XMP specification v1.3, Omni compiler v1.2.2 (2017) • XMP workshop, XMP specification v1.4, Omni compiler v1.3.2 (2018)	• Consideration of XcalableMP(XMP) specification and extension for OpenACC(XACC), and performance evaluation of Omni compilers	→

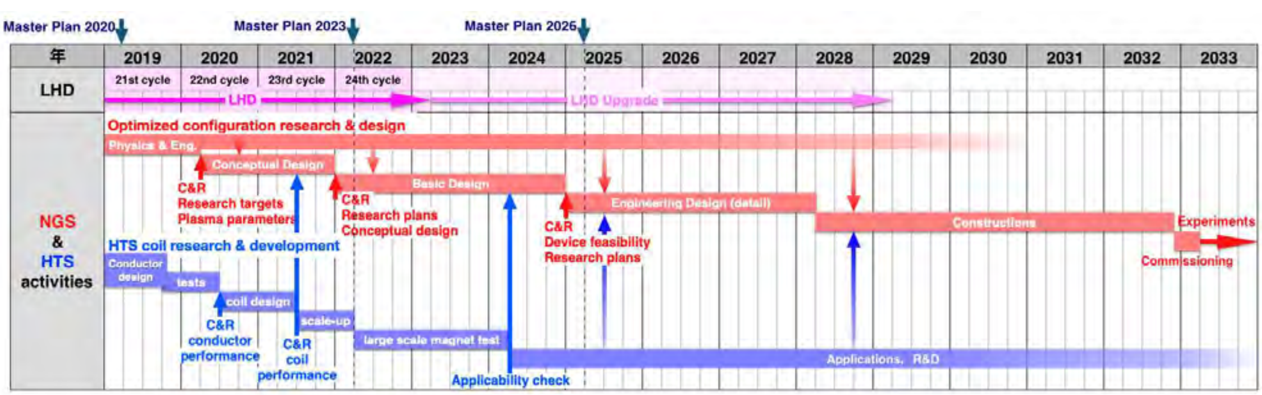
NSRP contributes to establishing the future plan of NIFS through applying simulation codes developed in NSRP to physics & engineering studies of optimized configuration for the Next Generation System (NGS) of the NIFS future plan

- Optimization of equilibrium for reducing NCL and turbulent transport
- Turbulence & Zonal flow modeling based on GK simulation
- Comparative study of modular-coils & helical-winding coils type optimizations
- Investigation of flexible divertor structures

Contributions to optimized configuration studies in Task force for next research project

- LHD has been operated for >20 years, and the future plans after LHD have been discussed since Apr. 2017 in Task force for next research project(次期計画検討チーム)
- Related research activities are initiated: NGS team & HTS team
  NGS: Physics & Engineering studies towards advanced optimizations.
  HTS: R&D of High-Temperature SC coils for application to the next device.
  → Simulation codes developed in NSRP are utilized in NGS activities.

Schedule towards the next device



*still discussed in Task force for next research project

Co-creation framework in optimized configuration research activities

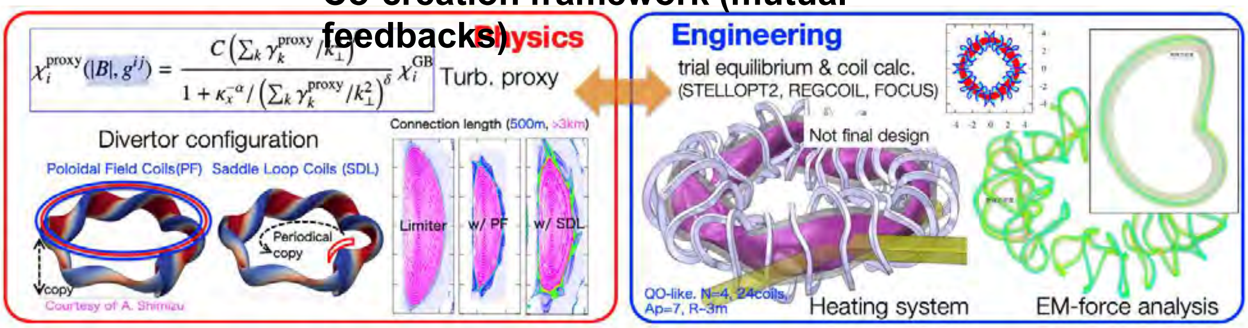
Physics studies for advanced concept

- NL-GK based turbulence modeling for stellarator optimizations
- Flexible divertor configuration (leg-type & island-type)
- Comparative study of modular-coils & helical-winding coils type optimizations

Engineering study with trial model case (coils, Vacu. Vessel, etc.)

- Trial-model-case engineering design with conventional schemes.
- Identification of engineering limits and boundary conditions.
- Design of heating systems, fundamental & advanced measurement system.

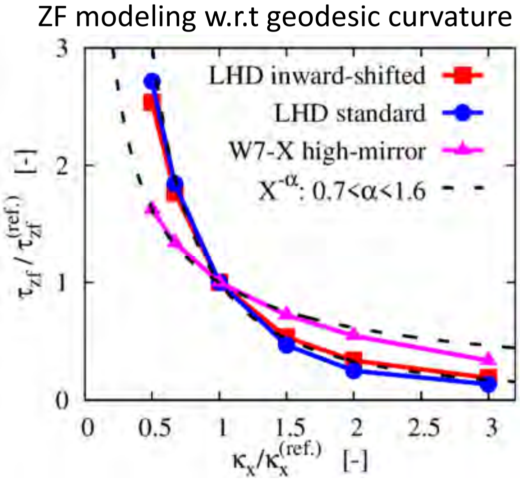
Co-creation framework (mutual feedbacks)



Turbulence & Zonal flow modeling for nonlinear optimizations

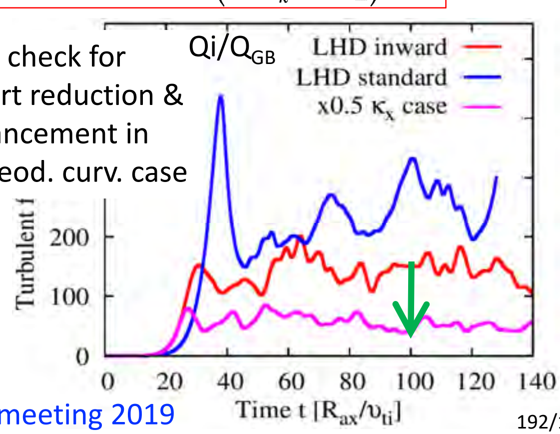
- Based on the gyokinetic simulation & modeling studies in NSRP, a new turbulence optimization model (proxy approach) is constructed.
- Extended turbulence proxy includes nonlinearity and ZF effects, which is beyond the conventional linear proxy approaches.
- It is now implementing to the optimizer code (e.g., STELLOPT).

ZF modeling w.r.t geodesic curvature



$$\chi_i^{\mathrm{proxy}}(|B|, g^{ij}) = \frac{C\left(\sum_k \gamma_k^{\mathrm{proxy}}/k_\perp^2\right)^\beta}{1 + \kappa_x^{-\alpha}/\left(\sum_k \gamma_k^{\mathrm{proxy}}/k_\perp^2\right)^\delta}\chi_i^{\mathrm{GB}}$$

NL-GKV check for transport reduction & ZF enhancement in lower geod. curv. case

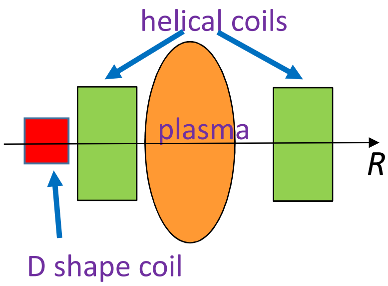


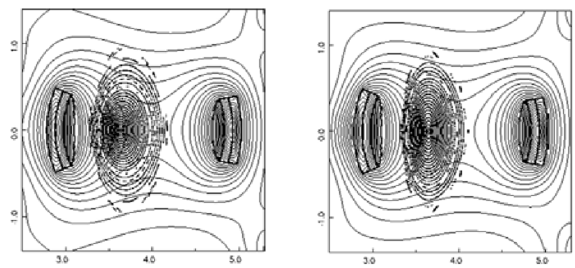
Nakata JIFT-WS2019, ISHW2019, EUROfusion Sci. meeting 2019

D shape coil current improves the divertor clearance.

skip

- Effects of the D shape deformation are investigated in the optimization of heliotron configurations.
- The vacuum magnetic field with the current in the D shape coil which is considered to be installed just inside the helical coils is analyzed.



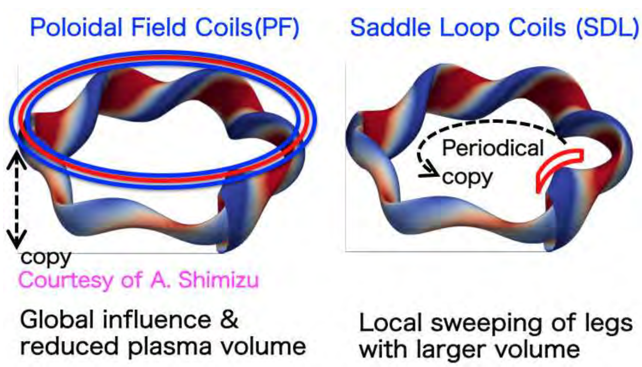


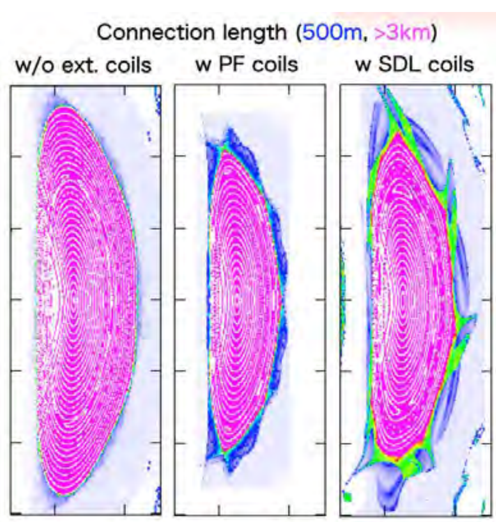
- The D shape coil current effectively enhances the divertor clearance.
- The effect is quite useful in the design of a smaller size device.
- On the other hand, the minor radius of the plasma is decreased due to the current.

Investigation of flexible divertor structures in a single optimized plasma

- In optimized stellarators, the divertor structure is often limited due to the complex coil configuration and the low-robustness against plasma beta.
- Promoting the optimized external coil study, the flexible control of leg-type divertor and island type divertor is investigated.
- Divertor properties are evaluated by e.g., the edge transport code (EMC3).

Sweeping the diverter-legs from Quasi-Symmetric stellarator (e.g., QH)



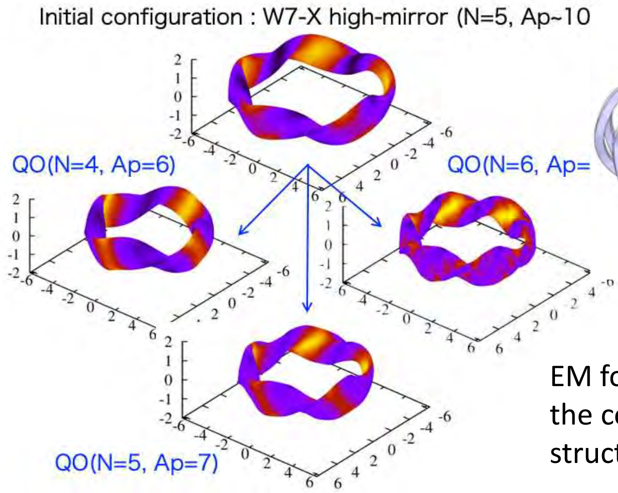


Nakata ISHW2019, Suzuki JSPF2019, Kawamura JSPF2019

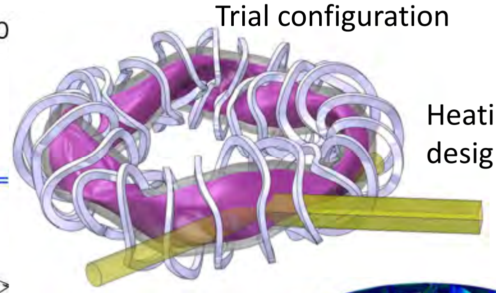
Optimization scan of the trial equilibrium for trial engineering design studies

- For engineering study with a trial equilibrium, optimization scan with STELLOPT and the evaluations of physical properties with drift/gyrokinetic, MHD codes are carried out.
- A QO-like neoclassically optimized equilibrium(Ap=7, N=4) are systematically selected as a trial configuration. → Pre-engineering design study is accelerated.

An example of STELLOPT scans

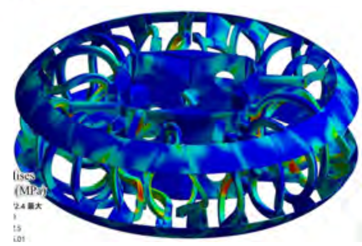


Trial configuration



Heating port design

EM force analysis for the coils and support structures



Matsuoka, Ichiguchi, Yamaguchi JSPF2019

Summary of Future Plan

The NSRP plans to further advance the researches for improving, integrating, and validating simulation codes with the upgraded Plasma Simulator toward construction of the Numerical Simulation Reactor

- Further improvement and integration of codes by collaboration among task groups and collaborators from other universities and institutes
- Validations of codes by comparison with experimental results of LHD and other devices by collaboration with the LHD Project and other institutes
- Contribution to further progress of fusion science and related science and engineering through advancing simulation methods and basis technology
- Application of the Numerical Simulation Reactor to design of high-performance helical fusion reactor under inter-project collaboration

The NSRP Contributes to the NIFS future plan through application of simulation codes developed in NSRP to physics & engineering studies of optimized configuration for the Next Generation System (NGS) under inter-project collaboration

- Turbulence & zonal flow modeling based on GK simulation to optimize equilibrium for reducing turbulent transport
- Comparative study of modular-coils & helical-winding coils type optimizations
- Investigation of flexible divertor structures

References

Table of Evaluation Results for the 2019 External Peer Review

Table of Evaluation Results for the 2019 External Peer Review "Numerical Simulation Reactor Research Project"

Ⅰ. Points for Evaluation

1. Development of research plan, system, and environment

(1)Does the Numerical Simulation Reactor Research Project (NSRP) appropriately set the goal and plan including the roadmap for construction of the Numerical Simulation Reactor? Are they properly discussed for accomplishing the third midterm target and plan?

(2)Does the research system function appropriately in accomplishing the objectives of the NSRP with attention to the management of step-by-step progress, research collaboration, and integration?

(3)Is the environment of the "Plasma Simulator" system and its related research appropriately developed and effectively utilized accordingly to the research plan? Is the installation of a higher performance supercomputer properly planned?

2. Research achievements

Does the NSRP produce high-level achievements in accordance with international standards for the following research areas described in the third midterm goal and plan by promoting theory and computer simulation research utilizing the Plasma Simulator?

(1)Construction of the Numerical Simulation Reactor, Validation and improvement of simulation codes through comparison to experimental results

(2)Academic systematization of fusion science and related science and engineering

(3)Are research achievements steadily made according to the plan of the NSRP?

3. Promotion of cooperation and collaboration

(1)Is collaboration research with universities based on theory and simulation research appropriately promoted? Does it contribute to the progress of the NSRP?

(2)Does the NSRP contribute to enhancing functions of universities and institutes as the center of excellence for fusion plasma simulation? Does the NSRP commit to the promotion of interdisciplinary collaboration and research?

(3)Does the NSRP contribute to international cooperation including ITER, BA activities, and others through international collaboration activities?

4. Human resources development

Does the NSRP contribute to the development of human resources required for maintaining high-level simulation research activities toward the future?

5. Future plan

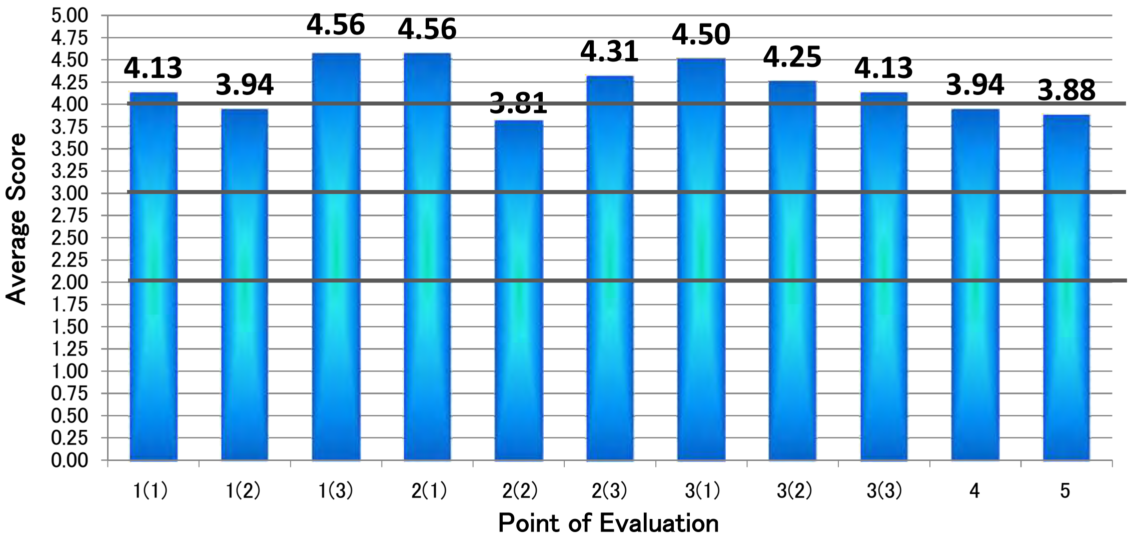
Is the future research plan suitable for progressing toward the goal of the NSRP?
Does it also contribute to establishing the future plan of the National Institute for Fusion Science?

Ⅱ. Tabele of Evaluation

Number of persons

Point of Evaluation / Score	1. Development of research plan, system, and environment			2. Research achievements			3. Promotion of cooperation and collaboration			4. Human resources development	5. Future plan
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)		
5 (Extremely highly commmendable)	4	2	10	10	0	6	8	6	4	3	4
4 (Highly commendable)	10	11	5	5	14	9	8	9	10	10	7
3 (Commendable)	2	3	1	1	1	1	0	0	2	2	4
2 (Adequate)	0	0	0	0	1	0	0	1	0	1	1
1 (Inadequate)	0	0	0	0	0	0	0	0	0	0	0
Average Score	4.13	3.94	4.56	4.56	3.81	4.31	4.50	4.25	4.13	3.94	3.88

※The evaluation result is a combination of the results of domestic committee members (12 and foreign committee members (4 persons).


Average Score
5.00
4.75
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1(1)
1(2)
1(3)
2(1)
2(2)
2(3)
3(1)
3(2)
3(3)
4
5
Point of Evaluation

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