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Prospects for Fusion Simulation Research Using IFERC-CSC HELIOS (Roku-chan)

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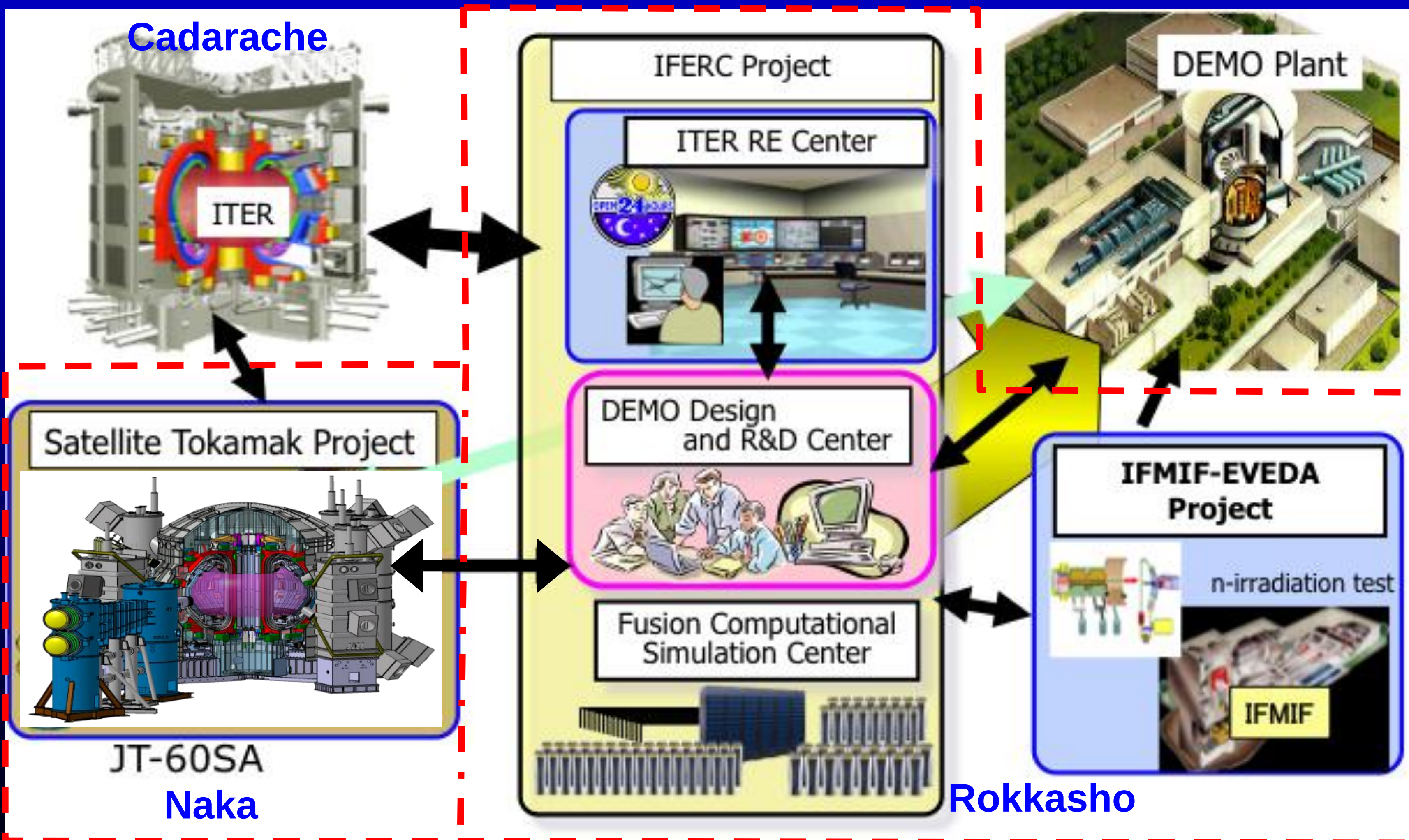
Contents

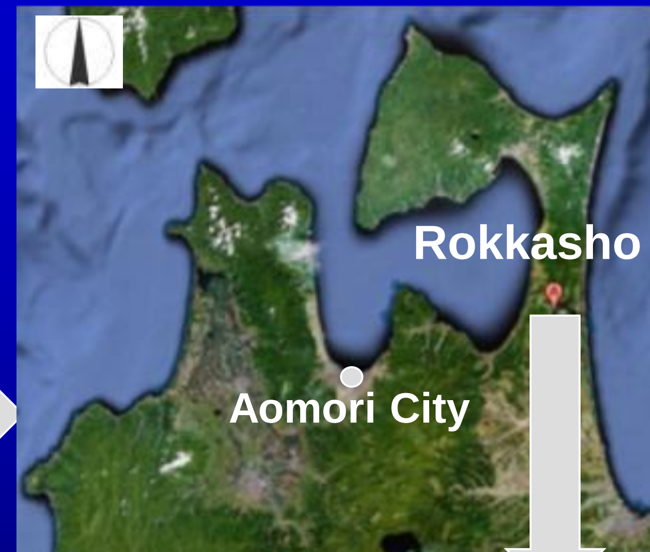
- BA IFERC-CSC
- BPSI (Burning Plasma Simulation Initiative)
- NEXT(Numerical EXperiment Tokamak)
- Prospects for Fusion Simulation Research using IFERC-CSC HELIOS

Broader Approach (BA) Activities

In parallel to the ITER program, BA activities are being implemented by the EU and Japan, aiming at early realization of the fusion energy



Rokkasho BA site



Rokkasho BA site

- Constructions of all buildings were completed by March 2010.

IFERC

International Fusion Energy Research Center
Computer Simulation Center

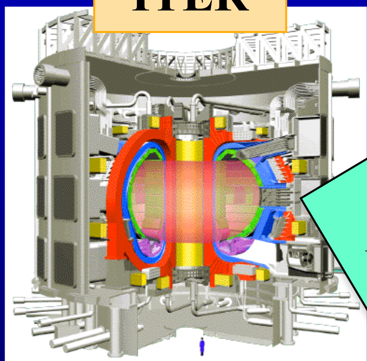
JAEA

FUSION FOR ENERGY

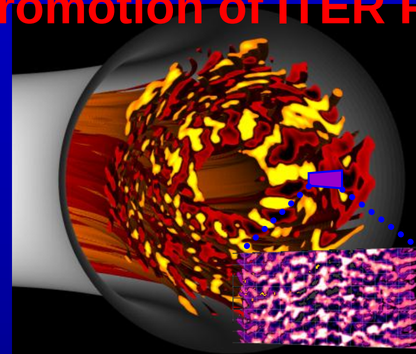
Simulation Research on Burning and Steady State Advanced Plasma Behaviors for ITER/Satellite Tokamak, Demo Reactor Design, Advanced Fusion Material Development, etc

➡ **Effective and Efficient Promotion of ITER Project and early Realization of Fusion Power Plant**

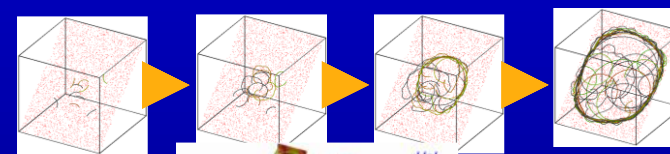
ITER

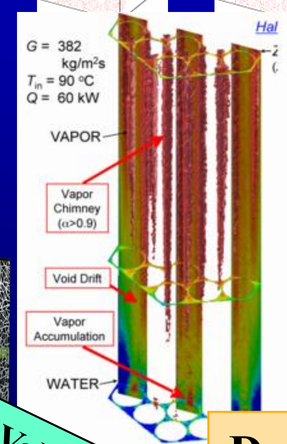


Plasma Behavior



Material Behavior

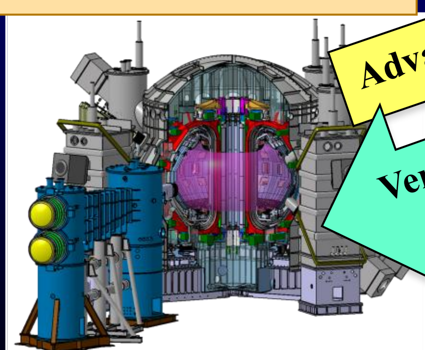




Two-phase Heat Flow

Burning Plasma Prediction

Satellite Tokamak



Advanced Plasma Data

Verification of Prediction

Design Validation

Required Conditions of Demo Reactor Design

Demo Reactor Design

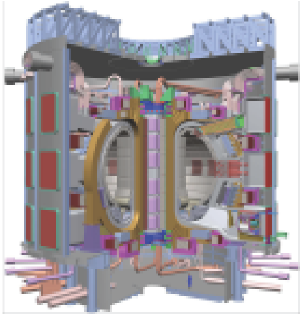
~1.5PF Super Computer

Contribution to Comprehensive Promotion of Demo Reactor Development

BPSI (Burning Plasma Simulation Initiative)

Establishment of quantitative description of burning plasmas in ITER

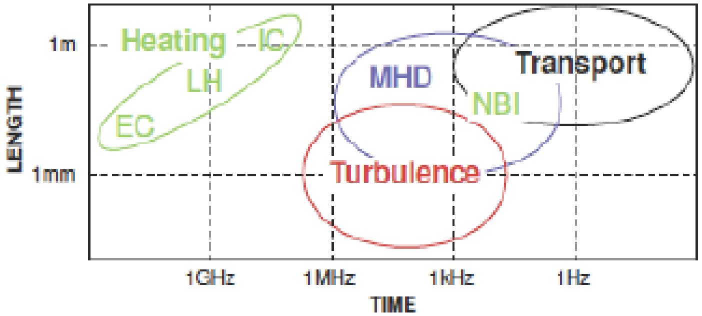
ITER

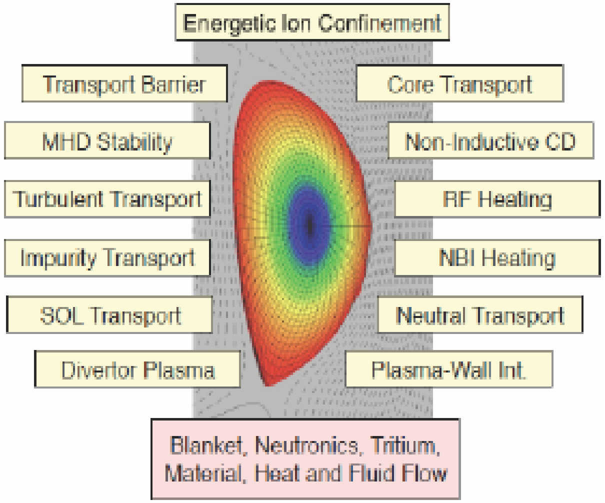


Development of integrated transport simulation with various modules

A. Fukuyama and M. Yagi, 'Burning Plasma Simulation Initiative and Its Recent Progress', J. Plasma Fusion Res. Vol.81, No.10 (2005) 747-754.

Reliable prediction and control



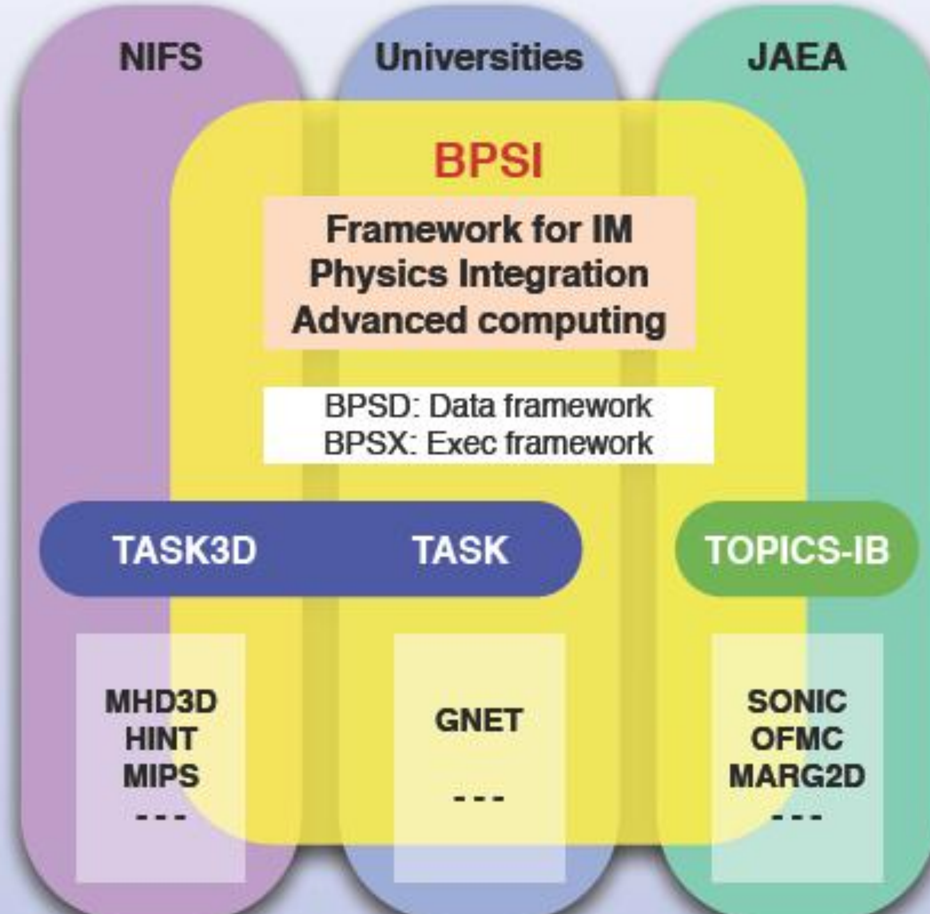


Time scale 10ps (100GHz)~1000s, spatial scale 10μm~10m

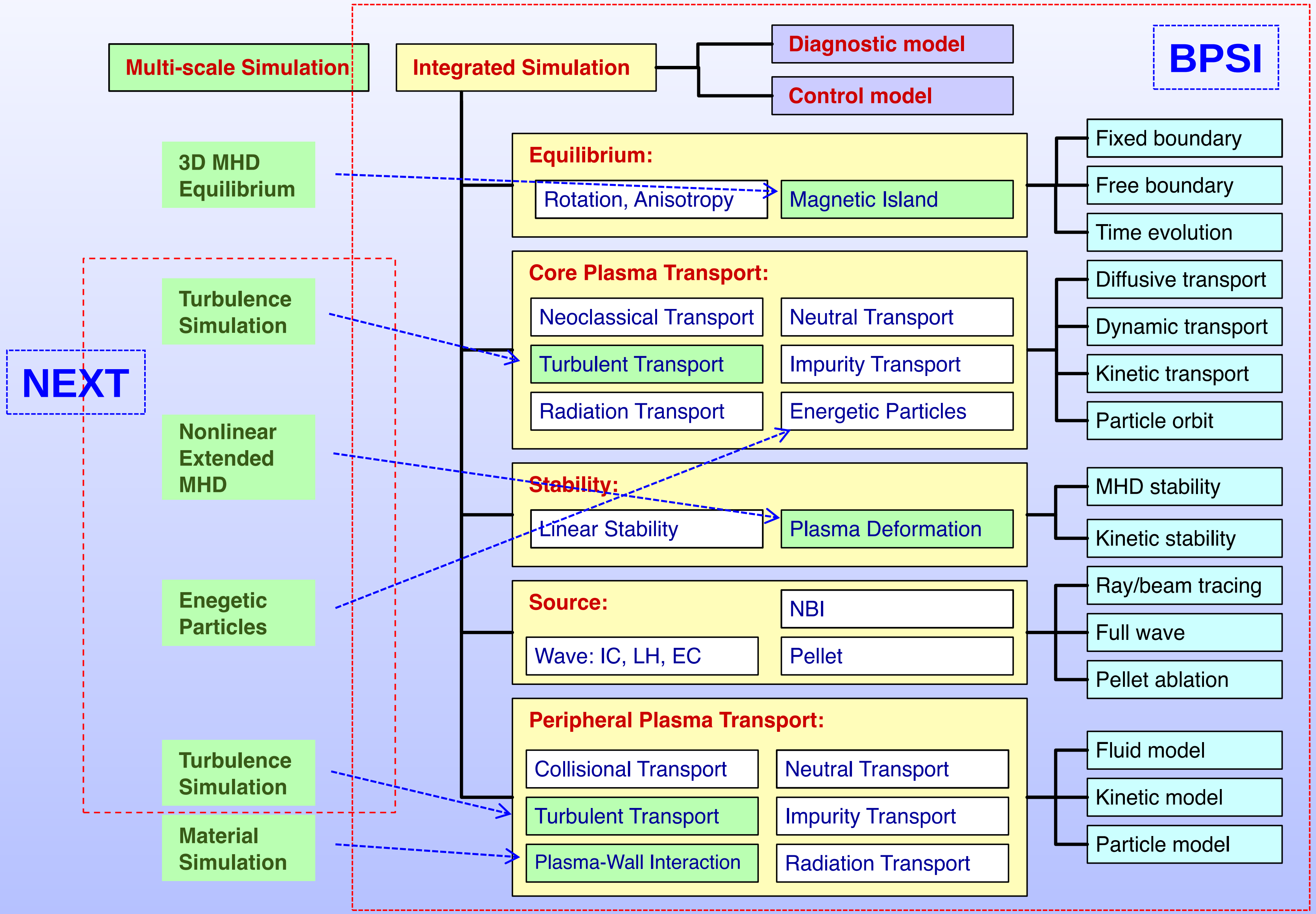
Burning plasma includes multi-scale, multi-physics phenomena

Integrated Modeling Activity in Japan

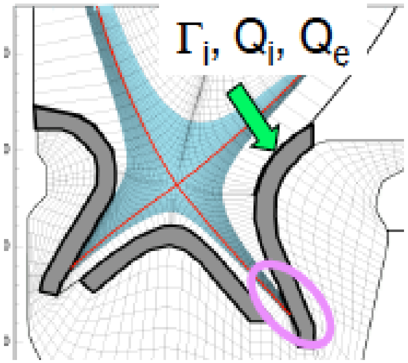
Burning Plasma Simulation Initiative (BPSI)
Research collaboration of universities, NIFS and JAEA

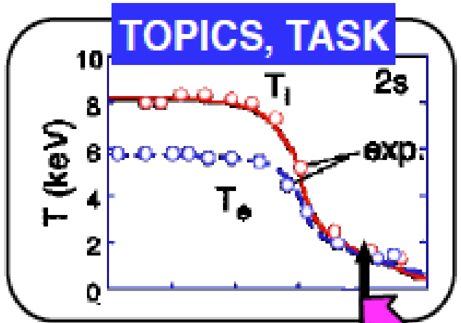


Integrated simulation



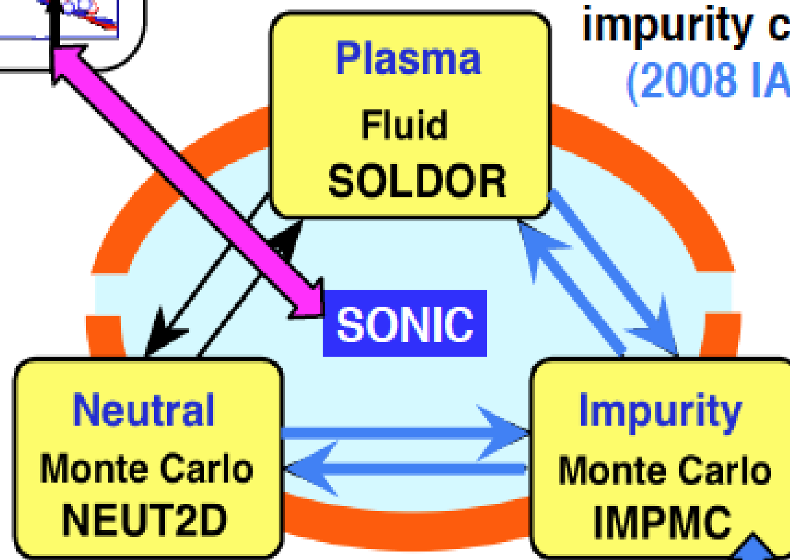
Integrated Divertor Code "SONIC"

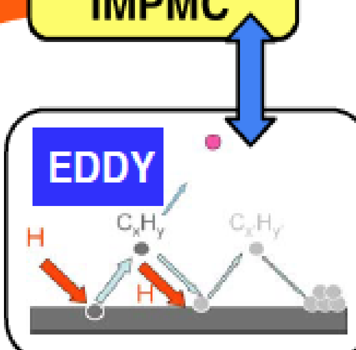




The divertor code is indispensable in divertor design work.

coupling of an MC impurity code (2008 IAEA)





- Interaction with core edge (2010 IAEA)

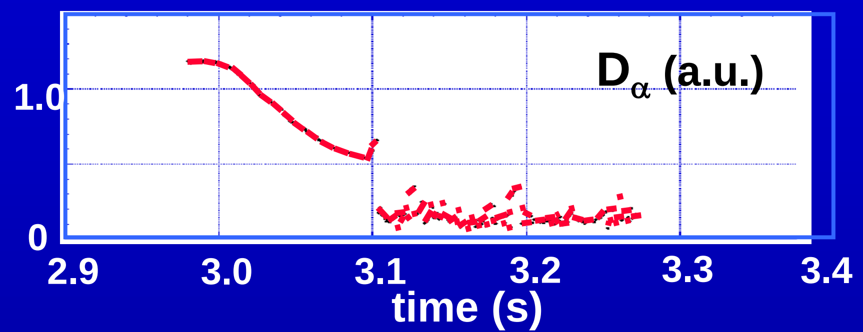
core transport $\xleftarrow{S_n, W_{cx}, W_{rad}}$ $\xrightarrow{F_i, Q_i, Q_e}$ SOL/divertor

SONIC has been consistently coupled to a 1.5 D tokamak transport code (TOPICS-IB and TASK).

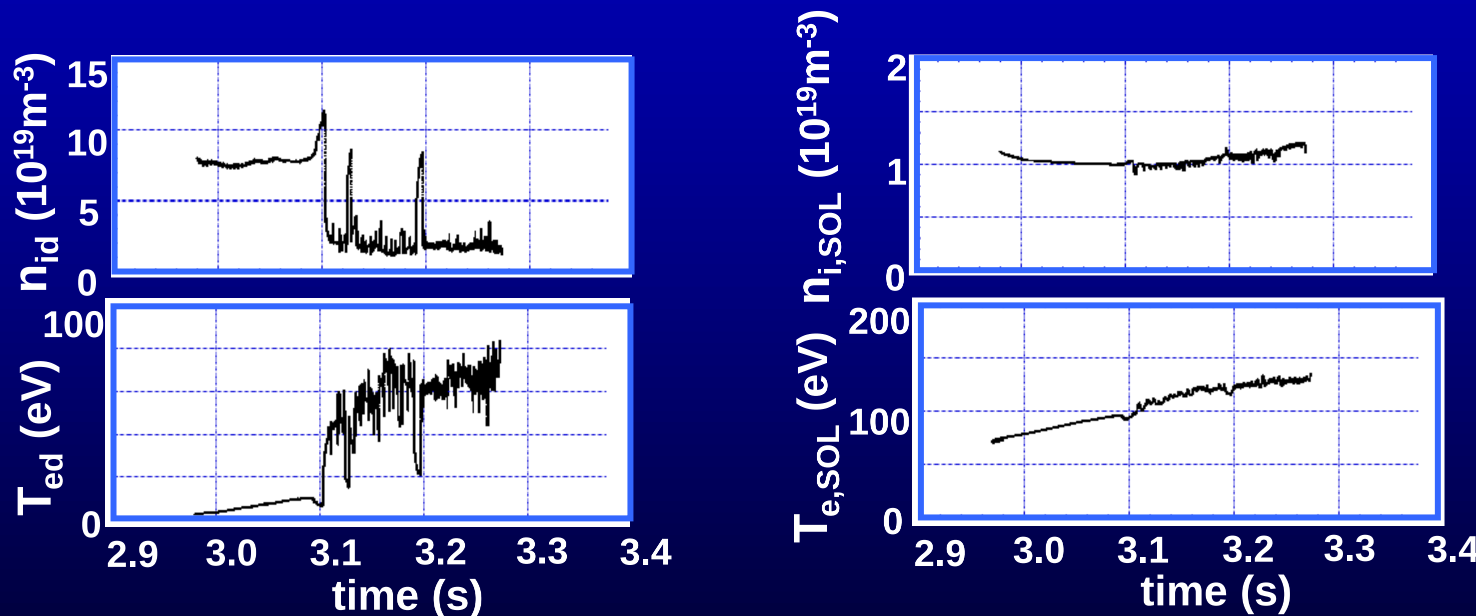
similar integrated codes : JINTRAC (EU) and FACETS (US)

Simulation of L-H Transition by TOPICS-IB+SONIC

Time evolution of D_α and Profiles by SONIC



M. Yagi et al (PET13,2011)



Time evolution of ion density and temperature (n_{id}, T_{ed}) at outer divertor strike point and ($n_{i,SOL}$, $T_{e,SOL}$) at outer mid-plane through the L/H transition.

Temporal fluctuation of SOL/divertor-plasma is observed in H-mode phase.

NEXT(<u>N</u>umerical <u>EX</u>periment of <u>T</u>okamak)

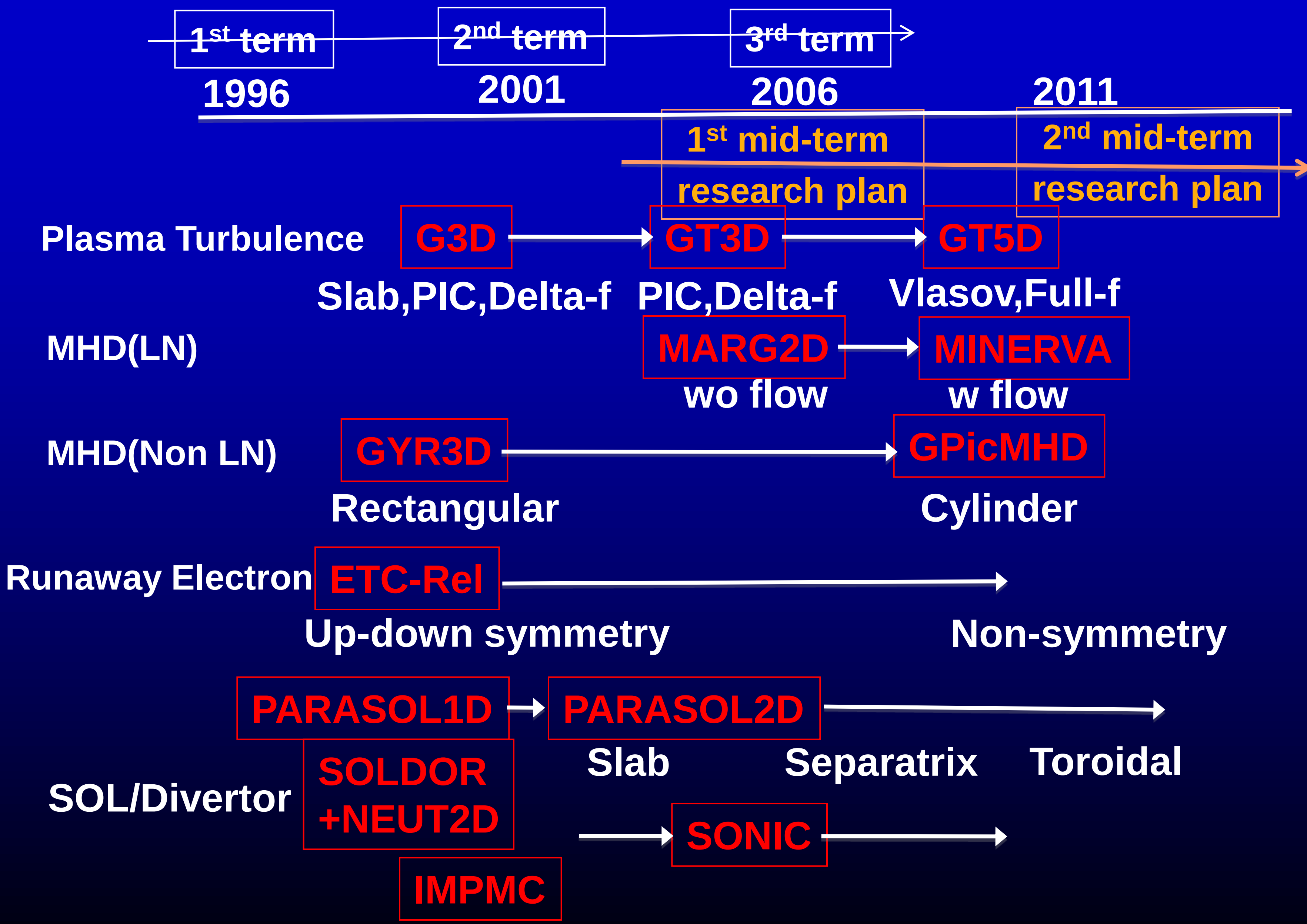
Objective:

Understanding the complex properties of fusion plasmas and predicting the physical processes in the next generation of tokamaks, such as ITER, using recently advanced computer resources.

To achieve our project, we are developing numerical simulation codes which are applicable for prediction of properties of the core plasma and the divertor plasma on equal footing.

GT5D, MINERVA,GPicMHD,ETC-Rel,PARASOL,SONIC, etc.

Code Development in NEXT Project



Physics Research in NEXT Project

1st term — 1996
2nd term — 2001
3rd term — 2006
2011

1st mid-term research plan
2nd mid-term research plan

Turbulence

ETG, ZF, K-H
ZF,GAM
GK Model w Flow
ITG (RS)
ETG, Streamer
ITG, Avalanche
Turbulence Statistics
EPM,TAE

MHD（Linear)

Stability (RS)
Peeling/Ballooning Mode
Resistive Wall Mode
Matching Theory for Rotating Plasma

MHD(Nonlinear)

Lagrangian Variational Principle
Nonlinear Double Tearing Mode
Spontaneous Reconnection
Forced Reconnection
Collisionless Kink
Disruption (RS)

Linear/Nonlinear MHD

- ✓ **Resistive Wall Mode (RWM)**

  Self-consistent treatment of equilibrium and stability in rotating plasmas

- ✓ **Edge Localized Mode (ELM)**

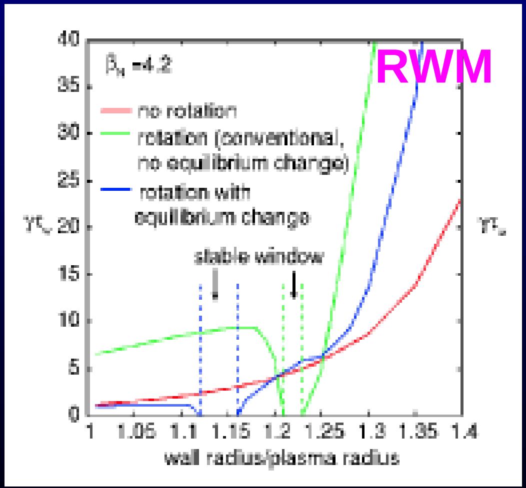
  Non-ideal effect on Peeling/Ballooning mode in rotating plasmas

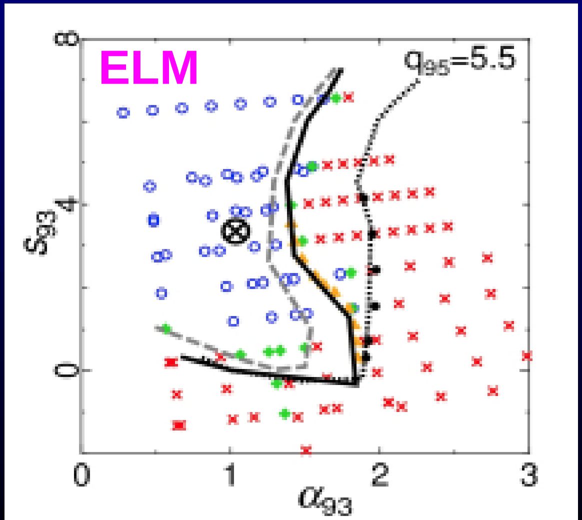
- ✓ **Collisionless Tearing Mode (CTM)**

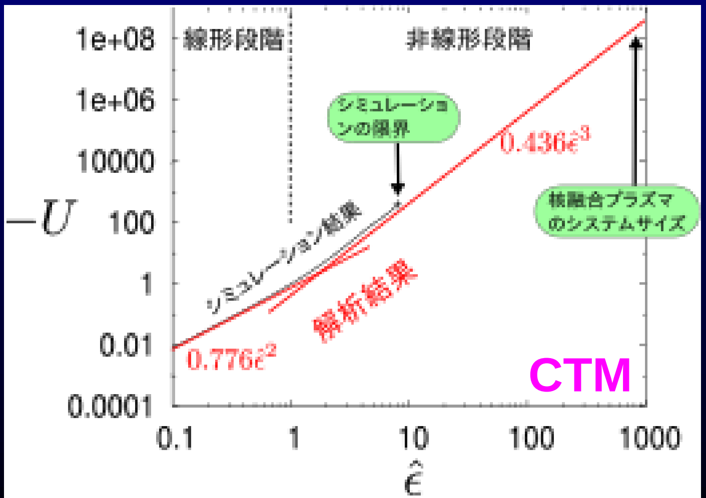
  Explosive growth of collisionless tearing mode based on variational principle

- ✓ **Energetic Particle Driven Mode (EPM)**

  Geometry effect, kinetic effect on EPM growth rate





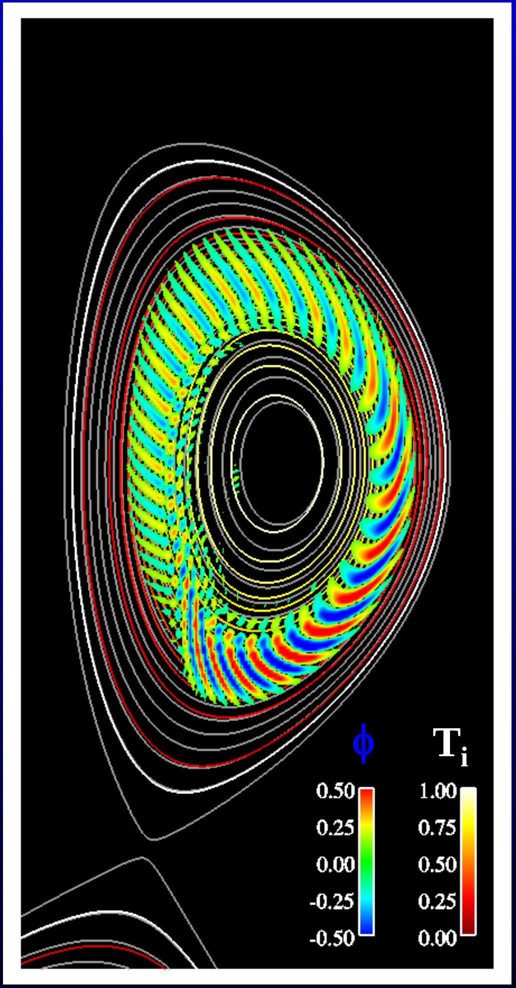


Gyrokinetic Toroidal 5D full-f Eulerian code GT5D

[Idomura, Comput.Phys.Commun. (2008); Nucl. Fusion (2009)]

- **GT5D code**
  - ✓ Global full-f gyrokinetic simulations of turbulent transport in ITG-TEM turbulence
  - ✓ 5D Eulerian code based on non-dissipative conservative FD scheme [Idomura,JCP07]
- **Verification**
  [Idomura,CPC08,Satake,CPC10,Camenen,NF10]
  - ✓ ITG-TEM benchmark (GT3D,GKW,etc…)
  - ✓ Neoclassical benchmark (FORTEC-3D)
- **Validation**
  [Idomura,NF09,IAEA10,Jolliet,IAEA10]
  - ✓ Avalanche-like non-local ion heat transport
  - ✓ Stiffness of ion temperature profile
  - ✓ Formation of intrinsic rotation
  - ✓ Scaling studies on ρ^*, safety factor, rotation

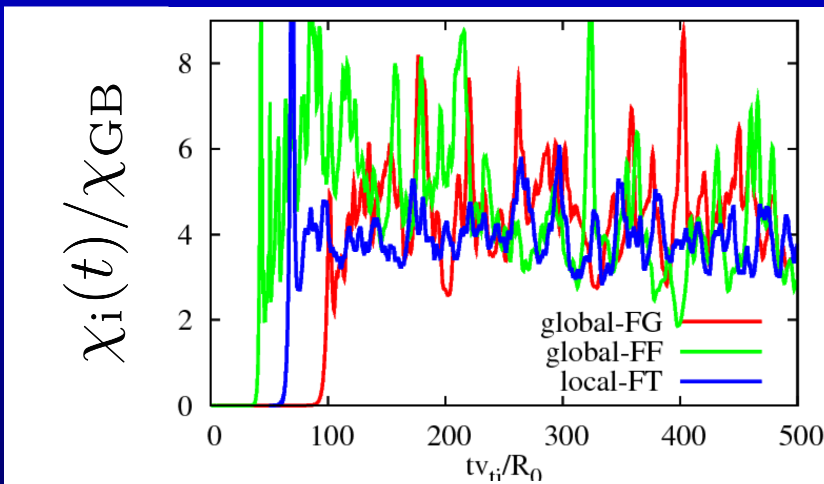
ITG mode in JT-60SA with ITER like shape

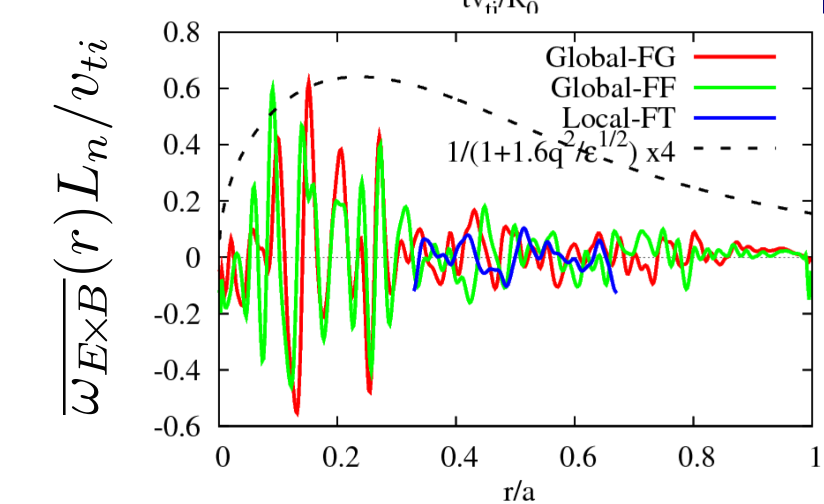


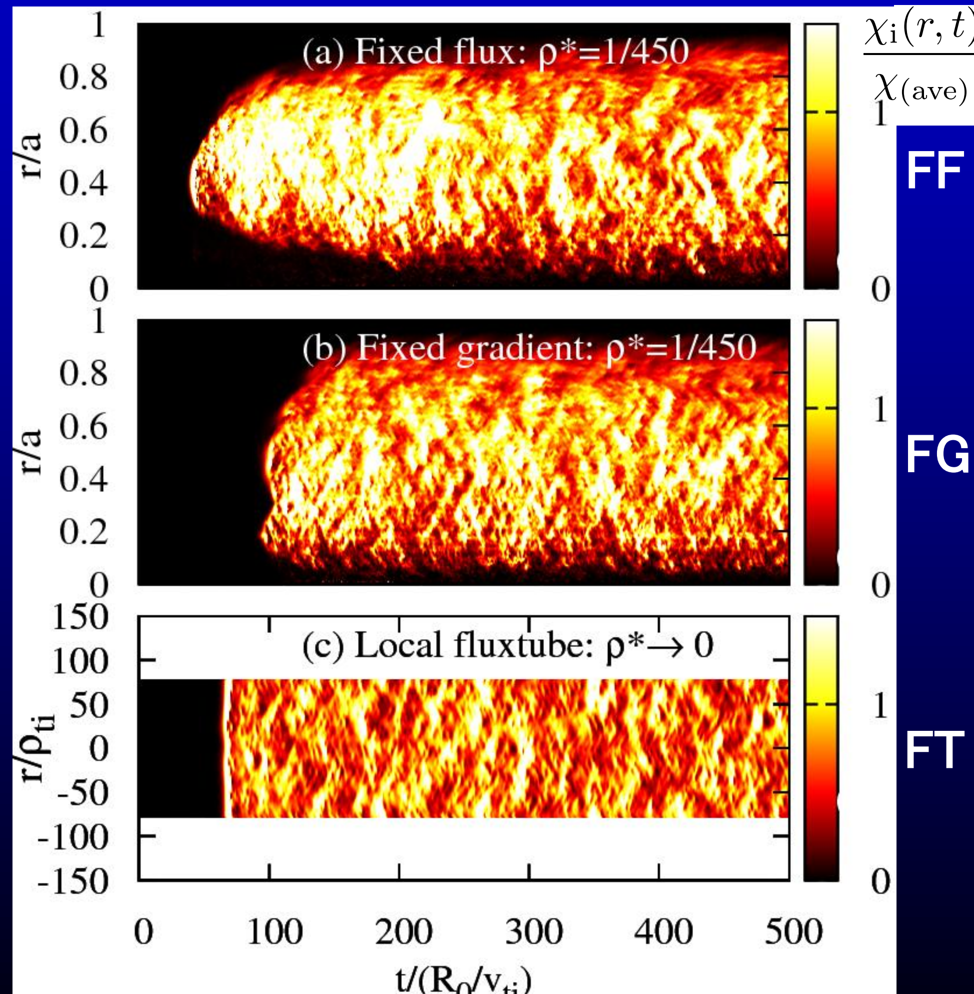
GT5D及びGKVを用いた大域および局所ジャイロ運動論的ITG乱流シミュレーションにおける輸送特性の比較 (Nakata et al, PS Symposium 2012)

- 大域的固定勾配(Fixed-Gradient)モデル
- 大域的固定熱流(Fixed-Flux)モデル
- 局所(FluxTube)モデル

局所漸近領域(ρ* =1/450)でのベンチマークにおいて、輸送レベルとゾーナルフロー構造の良い一致を確認。







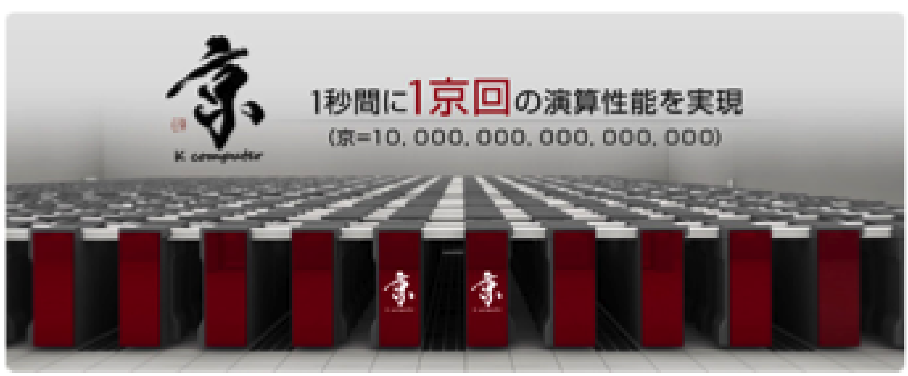
ペタスケール乱流計算に向けた並列計算手法開発

(Maeyama et al, PS Symposium 2012)

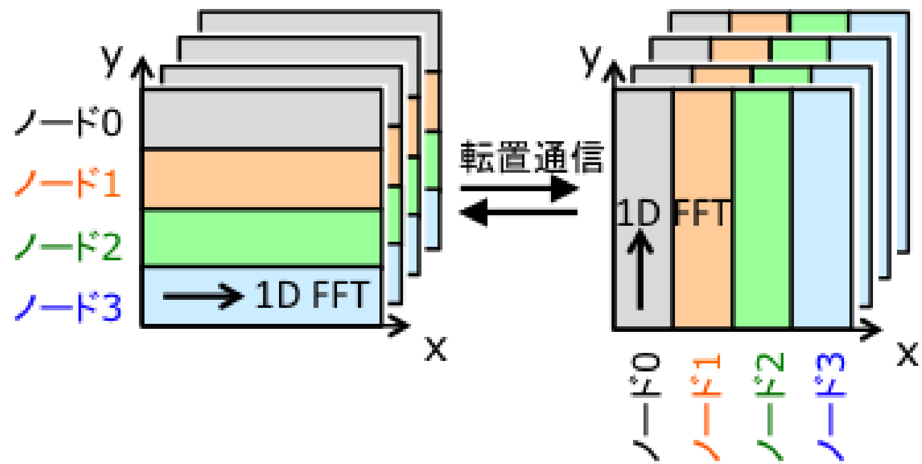
目的：ペタスケール大規模並列計算機を用いた乱流計算。

- 並列FFTの実装による並列数向上。
- 京の6次元トーラスネットワークに特化した通信最適化。
- 通信と演算の同時処理。

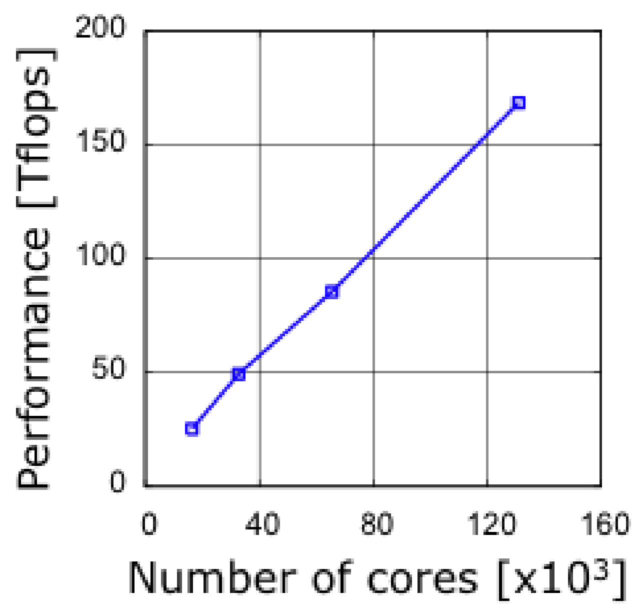
→ 10万コアを超えるストロングスケーリングを達成。
（並列化率 ～ 99.9998%）



並列2次元FFTの実装



京におけるGKVのストロングスケーリング



Disruption Integrated Code

Target: Starting from integration of MHD+runaway physics, DISRUPTION INTEGRATED CODE will be developed for self-consistent description of tokamak disruptions including runaway generation and confinement, first wall damage, and possible actuators.

Exp. Background: avoidance of runaway electrons by external helical fields in JT-60U

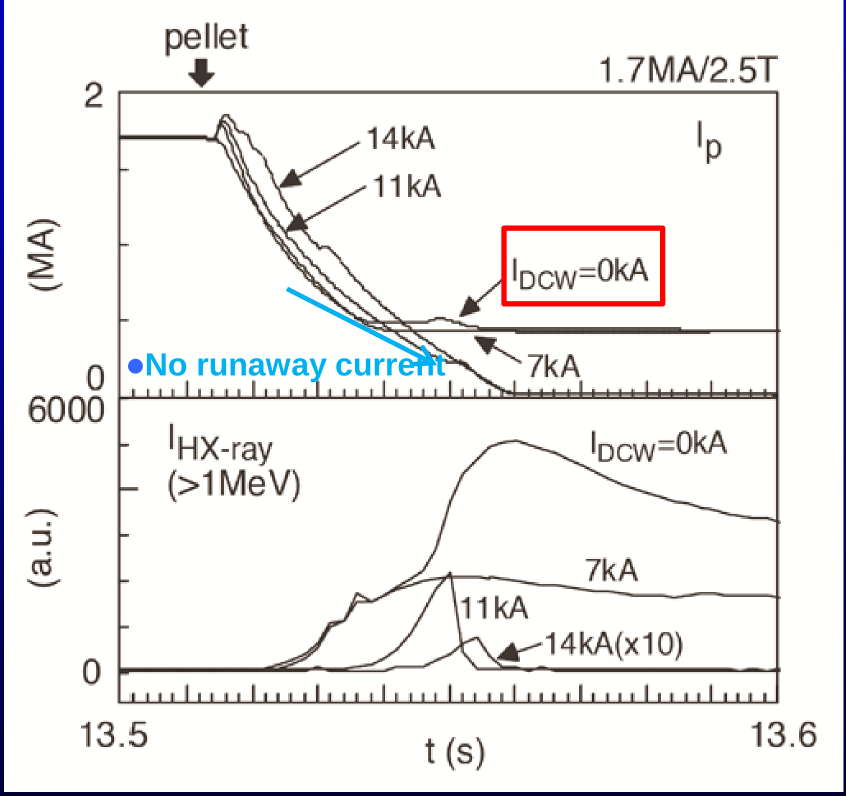
→ Involved physical mechanisms need to be studied by simulations!

Status and Plan (this 3 years):

1. Successful implementation of existing codes to Helios computer
   - ✓ Reduced MHD code (RMHD_4F_CYL)
   - ✓ Gyrokinetic PIC MHD code (GpicMHD)
   - ✓ Runaway electron following code (ETC-Rel)
2. Implementation of runaway physics models
   - ✓ Runaway acceleration and avalanche amplification
   - ✓ Synchrotron radiation and Bremsstrahlung

   ....

3. Integration of individual codes for multi-physics and multi-scale simulations
   - ✓ MHD + runaway
   - ✓ runaway + divertor

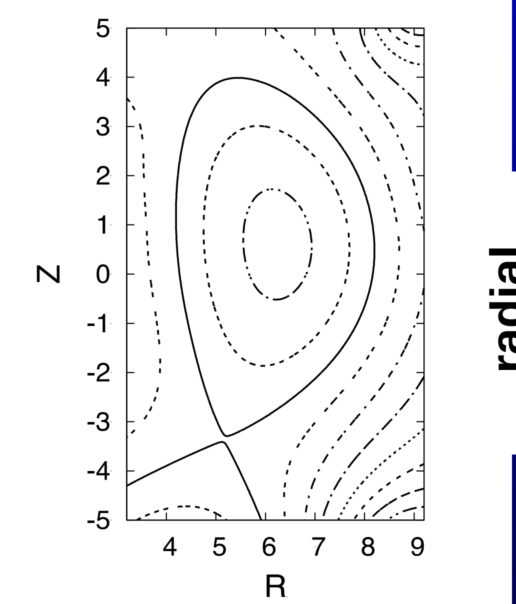


Suppression of runaway current generation was demonstrated with I_{DCW} with hard X-ray measurement (Kawano, et al., IAEA 1996).

Runaway electron confinement (ETC-Rel)

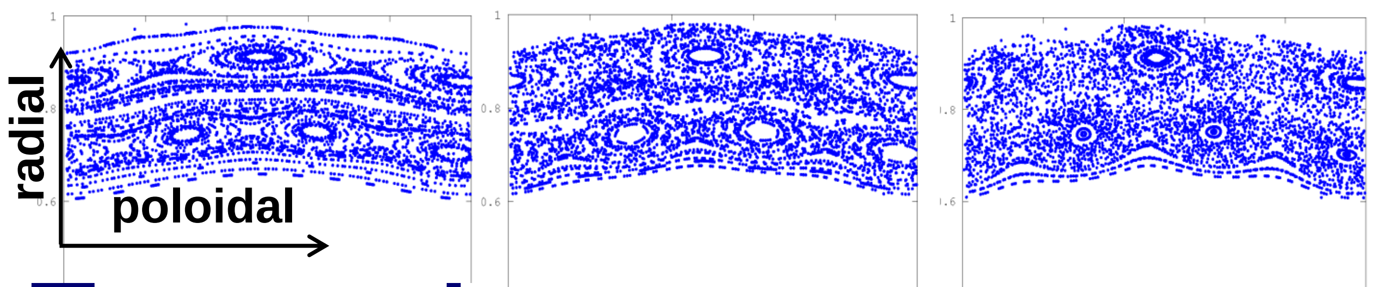
Relativistic electron following code, ETC-Rel (Tokuda and Yoshino, 1999) is currently being updated to study runaway electron confinement in ITER.

Ex. Simulation of runaway orbit trajectory in ITER-like up-down asymmetric equilibria



R = 6.2 m, a = 2m, B = 5.3 T

Overlapping of low m/n islands (where m/n=3/2 and 2/1) yields enhancement of orbit stochasticity (100 MeV electrons)



$w_{3/2} = w_{2/1} = 0.06$ $w_{3/2} = w_{2/1} = 0.08$ $w_{3/2} = w_{2/1} = 0.10$

Status of code development

- ✓ **Solving field line and relativistic drift Hamiltonian eqs. in real and Boozer coordinates**
- ✓ **Coupling with free-boundary MHD equilibrium code with up-down asymmetry**
- ✓ **MPI parallelization for Monte-Carlo simulations**

Prospects for Fusion Simulation Research using IFERC-CSC

Contributions by Plasma Simulation and Theory Group in JAEA

- **Plasma turbulence: improvement of GT5D, code (multi-spices, extension of GK model)**

  Realization of large scale and high performance turbulence simulation targeted for JT-60SA

- **MHD: extension to kinetic or extended MHD model**

  Realization of linear/nonlinear simulation of energetic particle driven mode such as EPM, EWM etc.

- **Disruption: development of integrated Disruption code including core, SOL/Divertor and conducting wall(error magnetic field)**

  Realization of vertical Disruption with self-consistent MHD interactions

Summary

- BA IFERC-CSC is implemented by EU and Japan.

Mission : To offer computer resource for large-scale and high performance fusion simulations aiming for effective and efficient promotion of ITER project and early realization of fusion power plant.

- BPSI is national integrated modeling activity(~2002) in Japan.

Objective: Establishment of quantitative description of burning plasmas in ITER.

- NEXT is numerical experiment of Tokamak project(~1996) in JAEA.

Objective: Understanding complex properties of fusion plasmas and prediction physical processes in next generation Tokamaks such as ITER and JT60SA.

- BPSI and NEXT (two halves of the whole) will contribute large-scale fusion simulation research making use of BA IFERC-CSC computer resource.