Recent Progress in Integrate Code TASK
— Integrated Modeling of —
– RF Heating and Current Drive in Tokamaks —

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in collaboration with
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Outline

• Integrated Simulation of Fusion Plasmas
• Progress of TASK Code Development
• Self-Consistent Analysis of RF Heating and Current Drive
• Full Wave Analysis Including FLR Effects
• Future Plan of Integrated Modeling
• Summary
Burning Plasma Simulation

Broad time scale:
100GHz ∼ 1000s

Broad Spatial scale:
10 μm ∼ 10m

One simulation code never covers all range.

Integrated simulation combining modeling codes interacting each other
Integrated Tokamak Simulation

Equilibrium:
- Magnetic Island
- Anisotropic Pressure

Core Plasma Transport:
- Neoclassical Transport
- Neutral Transport
- Turbulent Transport
- Impurity Transport
- Energetic Particles

Macroscopic Stability:
- Plasma Deformation

Wave Heating Current Drive:
- Wave Dispersion
- Velocity Distribution Fn

Peripheral Plasma Transport:
- Turbulent Transport
- Neutral Transport
- Plasma-Wall Interaction
- Impurity Transport
- Radiation Transport

Control model

Diagnostic model

Fixed boundary

Free boundary

Time evolution

Diffusive transport

Dynamic transport

Kinetic transport

Orbit following

MHD stability

Kinetic stability

Ray/Beam tracing

Full wave

Fluid transport

Kinetic transport
Multi-Hierarchy and Integrated Approaches

- Multi-Hierarchy Simulation
  - Device size
  - Magnetic island size
  - Ion gyroradius
  - Collisionless skin depth
  - Debye length
  - Electron gyroradius
  - Particle distance

- Integrated Simulation
  - Diagnostic model
  - Control model

  - Equilibrium:
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    - Anisotropic Pressure

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    - Radiation Transport

- Nonlinear MHD Simulation
- Extended MHD Simulation
- Turbulence Simulation
- Molecular Dynamics

Integrated Simulation

Nonlinear MHD Simulation
Extended MHD Simulation
Turbulence Simulation
Molecular Dynamics

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BPSI: Burning Plasma Simulation Initiative

Integrated code: TASK and TOPICS

NIFS

Universities

JAEA

BPSI

TASK/H

TASK

TOPICS

HINT MEGA

GNET GRM

OFMC MARG2D
TASK Code

- **Transport Analysing System for TokamaK**

- **Features**
  - Core of Integrated Modeling Code in BPSI
    - Modular structure
    - Reference data interface and standard data set
    - Uniform user interface
  - Various Heating and Current Drive Scheme
  - High Portability
  - Development using CVS (Concurrent Version System)
  - Open Source: [http://bpsi.nucleng.kyoto-u.ac.jp/task/](http://bpsi.nucleng.kyoto-u.ac.jp/task/)
  - Parallel Processing using MPI Library
  - Extension to Toroidal Helical Plasmas
Recent Progress of TASK

- **Fortran95**
  - **TASK V1.0**: Fortran95 compiler required (g95, pgf95, xlf95, ifort,...)
  - **TASK/EQ, TASK/TR**: Fortran95 (Module, Dynamic allocation)

- **Module structure**
  - **Standard dataset**: partially implemented
  - **Data exchange interface**: prototype
  - **Execution control interface**: prototype

- **New module**: from TOPICS by M. Azumi
  - **TOPICS/EQU**: Free boundary 2D equilibrium
  - **TOPICS/NBI**: Beam deposition + 1D Fokker-Planck
  - **MHD stability component**: coming

- **Self-consistent wave analysis**

- **Dynamic transport analysis**: by M. Honda
## Modules of TASK

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<th>2D Equilibrium</th>
<th>Fixed/Free boundary, Toroidal rotation</th>
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<td>TR</td>
<td>1D Transport</td>
<td>Diffusive transport, Transport models</td>
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<td>WR</td>
<td>3D Geometr. Optics</td>
<td>EC, LH: Ray tracing, Beam tracing</td>
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<td>WM</td>
<td>3D Full Wave</td>
<td>IC, AW: Antenna excitation, Eigenmode</td>
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<tr>
<td>FP</td>
<td>3D Fokker-Planck</td>
<td>Relativistic, Bounce-averaged</td>
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<td>DP</td>
<td>Wave Dispersion</td>
<td>Local dielectric tensor, Arbitrary $f(v)$</td>
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<tr>
<td>PL</td>
<td>Data Interface</td>
<td>Data conversion, Profile database</td>
</tr>
<tr>
<td>LIB</td>
<td>Libraries</td>
<td>LIB, MTX, MPI</td>
</tr>
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</table>

### Under Development

| TX  | Transport analysis including plasma rotation and $E_r$ |

### Collaboration with TOPICS

<table>
<thead>
<tr>
<th>EQU</th>
<th>Free boundary equilibrium</th>
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<tbody>
<tr>
<td>NBI</td>
<td>NBI heating</td>
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</tbody>
</table>
Inter-Module Collaboration Interface: TASK/PL

• Role of Module Interface
  ◦ Data exchange between modules:
    — Standard dataset: Specify set of data (cf. ITPA profile DB)
    — Specification of data exchange interface: initialize, set, get
  ◦ Execution control:
    — Specification of execution control interface:
      initialize, setup, exec, visualize, terminate
    — Uniform user interface: parameter input, graphic output

• Role of data exchange interface: TASK/PL
  ◦ Keep present status of plasma and device
  ◦ Store history of plasma
  ◦ Save into file and load from file
  ◦ Interface to experimental data database
Standard Dataset (interim)

**Shot data**
- Machine ID, Shot ID, Model ID

**Device data**: (Level 1)
- RR \( R \) m Geometrical major radius
- RA \( a \) m Geometrical minor radius
- RB \( b \) m Wall radius
- BB \( B \) m Vacuum toroidal mag. field
- RKAP \( \kappa \) T Elongation at boundary
- RDLT \( \delta \) T Triangularity at boundary
- RIP \( I_p \) A Typical plasma current

**Equilibrium data**: (Level 1)
- PSI2D \( \psi_p(R,Z) \) Tm\(^2\) 2D poloidal magnetic flux
- PSIT \( \psi_t(\rho) \) Tm\(^2\) Toroidal magnetic flux
- PSIP \( \psi_p(\rho) \) Tm\(^2\) Poloidal magnetic flux
- ITPSI \( I_t(\rho) \) Tm Poloidal current: \( 2\pi B_\phi R \)
- IPPSI \( I_p(\rho) \) Tm Toroidal current
- PPSI \( p(\rho) \) MPa Plasma pressure
- QINV \( 1/q(\rho) \) Inverse of safety factor

**Metric data**
- **1D**: \( V'(\rho), (\nabla V)(\rho), \ldots \)
- **2D**: \( g_{ij}, \ldots \)
- **3D**: \( g_{ij}, \ldots \)

**Fluid plasma data**
- NSMAX \( s \) Number of particle species
- PA \( A_s \) Atomic mass
- PZ0 \( Z_{0s} \) Charge number
- PZ \( Z_s \) Charge state number
- PN \( n_s(\rho) \) m\(^3\) Number density
- PT \( T_s(\rho) \) eV Temperature
- PU \( u_{s\phi}(\rho) \) m/s Toroidal rotation velocity
- QINV \( 1/q(\rho) \) Inverse of safety factor

**Kinetic plasma data**
- FP \( f(p,\theta_p,\rho) \) momentum dist. fn at \( \theta = 0 \)

**Dielectric tensor data**
- CEPS \( \epsilon(\rho,\chi,\zeta) \) Local dielectric tensor

**Full wave field data**
- CE \( E(\rho,\chi,\zeta) \) V/m Complex wave electric field
- CB \( B(\rho,\chi,\zeta) \) Wb/m\(^2\) Complex wave magnetic field

**Ray/Beam tracing field data**
- RRAY \( R(\ell) \) m \( R \) of ray at length \( \ell \)
- ZRAY \( Z(\ell) \) m \( Z \) of ray at length \( \ell \)
- PRAY \( \phi(\ell) \) rad \( \phi \) of ray at length \( \ell \)
- CERAY \( E(\ell) \) V/m Wave electric field at length \( \ell \)
- PWRAY \( P(\ell) \) W Wave power at length \( \ell \)
- DRAY \( d(\ell) \) m Beam radius at length \( \ell \)
- VRAY \( v(\ell) \) 1/m Beam curvature at length \( \ell \)
Data Exchange Interface

• **Data structure:** Derived type (Fortran95): structured type

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Fortran95 Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>time</td>
<td><code>plasmaf%time</code></td>
</tr>
<tr>
<td>number of grid</td>
<td><code>plasmaf%nrmax</code></td>
</tr>
<tr>
<td>e.g. square of grid radius</td>
<td><code>plasmaf%s(nr)</code></td>
</tr>
<tr>
<td>plasma density</td>
<td><code>plasmaf%data(nr)%pn</code></td>
</tr>
<tr>
<td>plasma temperature</td>
<td><code>plasmaf%data(nr)%pt</code></td>
</tr>
</tbody>
</table>

• **Program interface**

<table>
<thead>
<tr>
<th>Function</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initialize</td>
<td><code>bpsd_init_data(ierr)</code></td>
</tr>
<tr>
<td>e.g. Set data</td>
<td><code>bpsd_set_data('plasmaf',plasmaf,ierr)</code></td>
</tr>
<tr>
<td>Get data</td>
<td><code>bpsd_get_data('plasmaf',plasmaf,ierr)</code></td>
</tr>
</tbody>
</table>

• **Other functions:**
  ◦ Save data into a file, Load data from a file, Plot data
Execution Control Interface

- **Example for TASK/TR**

  - **TR_INIT** Initialization (Default value)  
    BPSX_INIT('TR')
  - **TR_PARM(ID,PSTR)** Parameter setup (Namelist input)  
    BPSX_PARM('TR', ID, PSTR)
  - **TR_SETUP(T)** Profile setup (Spatial profile, Time)  
    BPSX_SETUP('TR', T)
  - **TR_EXEC(DT)** Exec one step (Time step)  
    BPSX_EXEC('TR', DT)
  - **TR_GOUT(PSTR)** Plot data (Plot command)  
    BPSX_GOUT('TR', PSTR)
  - **TR_SAVE** Save data in file  
    BPSX_SAVE('TR')
  - **TR_LOAD** load data from file  
    BPSX_LOAD('TR')
  - **TR_TERM** Termination  
    BPSX_TERM('TR')

- **Module registration**

  - **TR_STRUCT%INIT=TR_INIT**
  - **TR_STRUCT%PARAM=TR_PARM**
  - **TR_STRUCT%EXEC=TR_EXEC**
  - ...
  - BPSX_REGISTER('TR', TR_STRUCT)
Example of data structure: \texttt{plasmaf}

type \texttt{bpsd\_plasmaf\_data} 
\begin{verbatim}
  real(8) :: pn ! Number density \([m^{-3}]\)
  real(8) :: pt ! Temperature [eV]
  real(8) :: ptpr ! Parallel temperature [eV]
  real(8) :: ptpp ! Perpendicular temperature [eV]
  real(8) :: pu ! Parallel flow velocity [m/s]
\end{verbatim}
end type \texttt{bpsd\_plasmaf\_data}

type \texttt{bpsd\_plasmaf\_type} 
\begin{verbatim}
  real(8) :: time
  integer :: nrmax ! Number of radial points
  integer :: nsmax ! Number of particle species
  real(8), dimension(:), allocatable :: s
     ! \((\rho^2)\) : normalized toroidal flux
  real(8), dimension(:), allocatable :: qinv
     ! \(1/q\) : inverse of safety factor
  type(bpsd\_plasmaf\_data), dimension(:,:,:), allocatable :: data
\end{verbatim}
end type \texttt{bpsd\_plasmaf\_type}
Examples of sequence in a module

- **TR_EXEC(dt)**

  ```plaintext
call bpsd_get_data('plasmaf',plasmaf,ierr)
call bpsd_get_data('metric1D',metric1D,ierr)
local data <- plasmaf,metric1D
advance time step dt
plasmaf <- local data
call bpsd_set_data('plasmaf',plasmaf,ierr)
  
- **EQ_CALC**

  ```plaintext
call bpsd_get_data('plasmaf',plasmaf,ierr)
local data <- plasmaf
calculate equilibrium
update plasmaf
call bpsd_set_data('plasmaf',plasmaf,ierr)
equ1D,metric1D <- local data
call bpsd_set_data('equ1D,equ1D,ierr)
call bpsd_set_data('metric1D',metric1D,ierr)
```
Example: Coupling of TASK/TR and TOPICS/EQU

- **TOPICS/EQU**: Free boundary 2D equilibrium
- **TASK/TR** Diffusive 1D transport (CDBM + Neoclassical)
- **QUEST** parameters:
  - $R = 0.64\, \text{m}$, $a = 0.36\, \text{m}$, $B = 0.64\, \text{T}$, $I_p = 300\, \text{kA}$, OH+LHCD

![Graphs and plots](image)
Transport simulation

- **OH + off-axis LHCD**: 200 kW
- **Formation of internal transport barrier** (equilibrium not solved)
Self-Consistent Wave Analysis with Modified $f(v)$

- **Modification of velocity distribution from Maxwellian**
  - Absorption of ICRF waves in the presence of energetic ions
  - Current drive efficiency of LHCD
  - NTM controllability of ECCD (absorption width)

- **Self-consistent wave analysis including modification of $f(v)$**
Self-Consistent ICRF Minority Heating Analysis

- **Analysis in TASK**
  - Dielectric tensor for arbitrary $f(v)$
  - Full wave analysis with the dielectric tensor
  - Fokker-Plank analysis of full wave results
  - Self-consistent iterative analysis: **Preliminary**

- **Energetic ion tail formation**
  - Broadening of power deposition profile

Momentum Distribution  Tail Formation  Power deposition

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![Graphs showing momentum distribution, tail formation, and power deposition](image)
FLR Effects in Full Waves Analyses

• Several approaches to describe the FLR effects.

• **Differential operators**: \( k_\perp \rho \rightarrow i\rho \partial / \partial r_\perp \)
  - This approach cannot be applied to the case \( k_\perp \rho \gtrsim 1 \).
  - Extension to the third and higher harmonics is difficult.

• **Spectral method**: Fourier transform in inhomogeneous direction
  - This approach can be applied to the case \( k_\perp \rho > 1 \).
  - All the wave field spectra are coupled with each other.
  - Solving a dense matrix equation requires large computer resources.

• **Integral operators**: \( \int \epsilon(x - x') \cdot E(x')dx' \)
  - This approach can be applied to the case \( k_\perp \rho > 1 \)
  - Correlations are localized within several Larmor radii
  - Necessary to solve a large band matrix
Full Wave Analysis
Using an Integral Form of Dielectric Tensor

• Maxwell’s equation:

\[ \nabla \times \nabla \times E(r) + \frac{\omega^2}{c^2} \int \leftrightarrow \epsilon(r, r') \cdot E(r') \, d\mathbf{r} = \mu_0 j_{ext}(r) \]

• Integral form of dielectric tensor: \( \leftrightarrow \epsilon(r, r') \)
  ○ Integration along the unperturbed cyclotron orbit

• 1D analysis in tokamaks (in the direction of major radius)
  ○ To confirm the applicability of an integral form of dielectric tensor
  ○ Another formulation in the lowest order of \( \rho/L \)

• 2D analysis in tokamaks
  ○ In more realistic configurations
One-Dimensional Analysis

ICRF minoring heating with $\alpha$-particles ($n_D : n_{He} = 0.96 : 0.02$)

Differential form

Integral form

$R_0 = 3.0\text{m}$

$a = 1.2\text{m}$

$B_0 = 3\text{T}$

$T_{e0} = 10\text{keV}$

$T_{D0} = 10\text{keV}$

$T_{\alpha0} = 3.5\text{MeV}$

$n_{s0} = 10^{20}\text{m}^{-3}$

$\omega/2\pi = 45\text{MHz}$

Absorption by $\alpha$ may be overestimated by differential approach.
2-D Formulation

• Coordinates
  ○ Magnetic coordinate system: \((\psi, \chi, \zeta)\)
  ○ Local Cartesian coordinate system: \((s, p, h)\)
  ○ Fourier expansion: poloidal and toroidal mode numbers, \(m, n\)

• Perturbed current

\[
j(r, t) = -\frac{q}{m} \int dv q v \int_{-\infty}^{\infty} dt' \left[ E(r', t') + v' \times B(r', t') \right] \cdot \frac{\partial f_0(v')}{\partial v'}
\]

• The time evolution of \(\chi\) and \(\zeta\) due to gyro-motion

\[
\begin{align*}
\chi(t - \tau) &= \chi(t) + \frac{\partial \chi}{\partial s} v_\perp \left\{ \cos(\omega_c \tau + \theta_0) - \cos \theta_0 \right\} + \frac{\partial \chi}{\partial p} v_\perp \left\{ \sin(\omega_c \tau + \theta_0) - \sin \theta_0 \right\} - \frac{\partial \chi}{\partial h} v_\parallel \tau \\
\zeta(t - \tau) &= \zeta(t) + \frac{\partial \zeta}{\partial s} v_\perp \left\{ \cos(\omega_c \tau + \theta_0) - \cos \theta_0 \right\} + \frac{\partial \zeta}{\partial p} v_\perp \left\{ \sin(\omega_c \tau + \theta_0) - \sin \theta_0 \right\} - \frac{\partial \zeta}{\partial h} v_\parallel \tau
\end{align*}
\]
Variable Transformations

- **Transformation of Integral Variables**
  - Transformation from the velocity space variables \((v_\perp, \theta_0)\) to the particle position \(s'\) and the guiding center position \(s_0\).

  - Jacobian: \(J = \frac{\partial(v_\perp, \theta_0)}{\partial(s', s_0)} = -\frac{\omega_c^2}{v_\perp \sin \omega_c \tau}\).

- **Integration over \(\tau\)**
  - Integral in time calculated by the Fourier series expansion with cyclotron period, \(2\pi/\omega_c\).

- **Integration over \(v_\parallel\)**
  - Interaction between wave and particles along the magnetic field lines described by the plasma dispersion function.
Final Form of Induced Current

- **Induced current**:

  \[ \vec{\mu}^{-1} \cdot \begin{pmatrix} J_{1}^{mn}(\psi) \\ J_{2}^{mn}(\psi) \\ J_{3}^{mn}(\psi) \end{pmatrix} = \int du' \int du_0 \vec{\varphi}(u, u', u_0) \cdot \begin{pmatrix} E_{1}^{m'n}(\psi) \\ E_{2}^{m'n}(\psi) \\ E_{3}^{m'n}(\psi) \end{pmatrix} \]

- **Electrical conductivity**:

  \[ \vec{\varphi}(u, u', u_0) = -i \left( \frac{1}{2\pi} \right)^{\frac{\pi}{2}} n_0 \frac{q^2}{m} \sum_{m'} \sum_{n'} \int d\chi \int d\zeta \exp \{ (m' - m)\chi + (n' - n)\zeta \} \vec{\mathcal{H}}(u, u', \chi) \]

- **Matrix coefficients**:

  \[ H_{1i} = \left( Q_3 \mu_{1i}^{-1} - u' Q_1 \mu_{2i}^{-1} \right) \sqrt{\frac{\pi}{2 k||}} Z(\eta_i) + \left[ -\frac{Q_1 v_{T\perp}^2}{v_{T\parallel}^2} \mu_{3i}^{-1} + \left( 1 - \frac{v_{T\perp}^2}{v_{T\parallel}^2} \right) \right] \left\{ Q_3 \kappa_{2i} + Q_1 u' \kappa_{1i} \right\} \sqrt{\frac{\pi}{2 k||}} Z'(\eta_i) \]

  \[ H_{2i} = \left( -Q_2 u \mu_{1i}^{-1} + Q_0 u' \mu_{2i}^{-1} \right) \sqrt{\frac{\pi}{2 k||}} Z(\eta_i) + \left[ \frac{Q_0 u v_{T\perp}^2}{v_{T\parallel}^2} \mu_{3i}^{-1} - \left( 1 - \frac{v_{T\perp}^2}{v_{T\parallel}^2} \right) \right] u \left\{ Q_2 \kappa_{2i} + Q_0 u' \kappa_{1i} \right\} \sqrt{\frac{\pi}{2 k||}} Z'(\eta_i) \]

  \[ H_{3i} = \left( -\frac{Q_2}{v_{T\perp}} \mu_{1i}^{-1} + \frac{Q_0 u'}{v_{T\perp}} \mu_{2i}^{-1} \right) \sqrt{\frac{\pi}{2 k||}} Z'(\eta_i) + \left[ -\frac{Q_0}{v_{T\parallel}} \mu_{3i}^{-1} + \frac{v_{T\parallel}}{v_{T\perp}} \left( 1 - \frac{v_{T\perp}^2}{v_{T\parallel}^2} \right) \right] \left\{ Q_2 \kappa_{2i} + Q_0 u' \kappa_{1i} \right\} \sqrt{\frac{\pi}{2 k||}} \eta_i Z'(\eta_i) \]
Kernel Functions

- Kernel functions

\[ Q \left( \begin{array}{c} 0 \\ 1 \\ 2 \\ 3 \end{array} \right) (u, u', \chi_0, l) = \int_0^{2\pi} d\lambda \frac{1}{|\sin \lambda|} \begin{pmatrix} 1 \\ V_1 \\ V_2 \\ V_1 V_2 \end{pmatrix} \]

\[ \times \exp i \left[ \frac{k_{\perp} v_{T_{\perp}}}{\omega_c} \left\{ (V_2 - V_1) \cos \alpha - (u - u') \sin \alpha \right\} + l\lambda - \frac{V_{0^2}}{2} \right] \]

\[ V_0^2 = \left( \frac{u + u'}{2} \right)^2 \frac{1}{\cos^2 \frac{1}{2}\lambda} + \left( \frac{u - u'}{2} \right)^2 \frac{1}{\sin^2 \frac{1}{2}\lambda} \]

\[ V_1 = \frac{u - u'}{2} \tan \frac{1}{2}\lambda - \frac{u + u'}{2} \tan \frac{1}{2}\lambda \]

\[ V_2 = \frac{u - u'}{2} \tan \frac{1}{2}\lambda + \frac{u + u'}{2} \tan \frac{1}{2}\lambda \]

where \( k = \mu^{-1} \cdot g \cdot h \), \( \mu \) is the transformation matrix for \((s, p, h) \rightarrow (\psi, \chi, \zeta)\), and \( g \) is the metric tensor.
Consistent Formulation of Integral Full Wave Analysis

• Analysis of wave propagation
  ◦ Dielectric tensor:
    \[
    \nabla \times \nabla \times E(r) - \frac{\omega^2}{c^2} \int dr_0 \int dr' \frac{p' \partial f_0(p', r_0)}{m\gamma} \cdot K_1(r, r', r_0) \cdot E(r') = i \omega \mu_0 j_{\text{ext}}
    \]
    where \( r_0 \) is the gyrocenter position.

• Analysis of modification of momentum distribution function
  ◦ Quasi-linear operator
    \[
    \frac{\partial f_0}{\partial t} + \frac{\partial}{\partial p} \int dr \int dr' E(r) E(r') \cdot K_2(r, r', r_0) \frac{\partial f_0(p', r_0, t)}{\partial p'} = \left( \frac{\partial f_0}{\partial p} \right)_{\text{col}}
    \]
  • The kernels \( K_1 \) and \( K_2 \) are closely related and localized in the region \(|r - r_0| \lesssim \rho\) and \(|r' - r_0| \lesssim \rho\).
Extension to TASK/3D

• **3D Equilibrium:**
  ◦ Interface to equilibrium data from VMEC or HINT
  ◦ Interface to neoclassical transport coefficient codes

• **Modules 3D-ready:**
  ◦ **WR**: Ray and beam tracing
  ◦ **WM**: Full wave analysis

• **Modules to be updated:**
  ◦ **TR**: Diffusive transport (with an appropriate model of $E_r$)
  ◦ **TX**: Dynamic transport (with neoclassical toroidal viscosity)

• **Modules to be added**: *(by Y. Nakamura)*
  ◦ **EI**: Time evolution of current profile in helical geometry
## Road map of TASK code

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<th>Module</th>
<th>Present Status</th>
<th>In 2 years</th>
<th>In 5 years</th>
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<td>Equilibrium</td>
<td>Fixed/Free Boundary</td>
<td>Equilibrium Evolution</td>
<td>Start Up Analysis</td>
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<tr>
<td>Core Transport</td>
<td>1D Diffusive TR</td>
<td>Kinetic TR</td>
<td>2D Fluid TR</td>
</tr>
<tr>
<td></td>
<td>1D Dynamic TR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOL Transport</td>
<td>2D Fluid TR</td>
<td></td>
<td>Plasma-Wall Interaction</td>
</tr>
<tr>
<td>Neutral Transport</td>
<td>1D Diffusive TR</td>
<td>Orbit Following</td>
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<tr>
<td>Energetic Ions</td>
<td>Kinetic Evolution</td>
<td>Orbit Following</td>
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<tr>
<td>Wave Beam</td>
<td>Ray/Beam Tracing</td>
<td>Beam Propagation</td>
<td></td>
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<tr>
<td>Full Wave</td>
<td>Kinetic $\epsilon$</td>
<td>Gyro Integral $\epsilon$</td>
<td>Orbit Integral $\epsilon$</td>
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<tr>
<td>Stabilities</td>
<td>Sawtooth Osc.</td>
<td>Tearing Mode</td>
<td>Systematic Stability Analysis</td>
</tr>
<tr>
<td></td>
<td>ELM Model</td>
<td>Resistive Wall Mode</td>
<td></td>
</tr>
<tr>
<td>Turbulent Transport</td>
<td>CDBM Model</td>
<td>Linear GK + ZF</td>
<td>Nonlinear ZK + ZF</td>
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<td>Diagnostic Module</td>
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<td>Control Module</td>
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Summary

• We are developing **TASK** code as a reference core code for integrated burning plasma simulation based on transport analysis.

• We have developed a part of **standard dataset, data exchange interface and execution control** and implemented them in **TASK** code. An example of coupling between **TOPICS/EQU** and **TASK/TR** was shown, though not yet completed. Some other modules of **TOPICS** will be incorporated soon.

• Preliminary results of **self-consistent analysis of wave heating and current drive** describing the time evolution of the momentum distribution function and **Integro-differential full wave analysis including FLR effects** have been obtained.

• Further continuous development of integrated modeling is needed for comprehensive **ITER** simulation.