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Present Status and Future Plan of TASK Code

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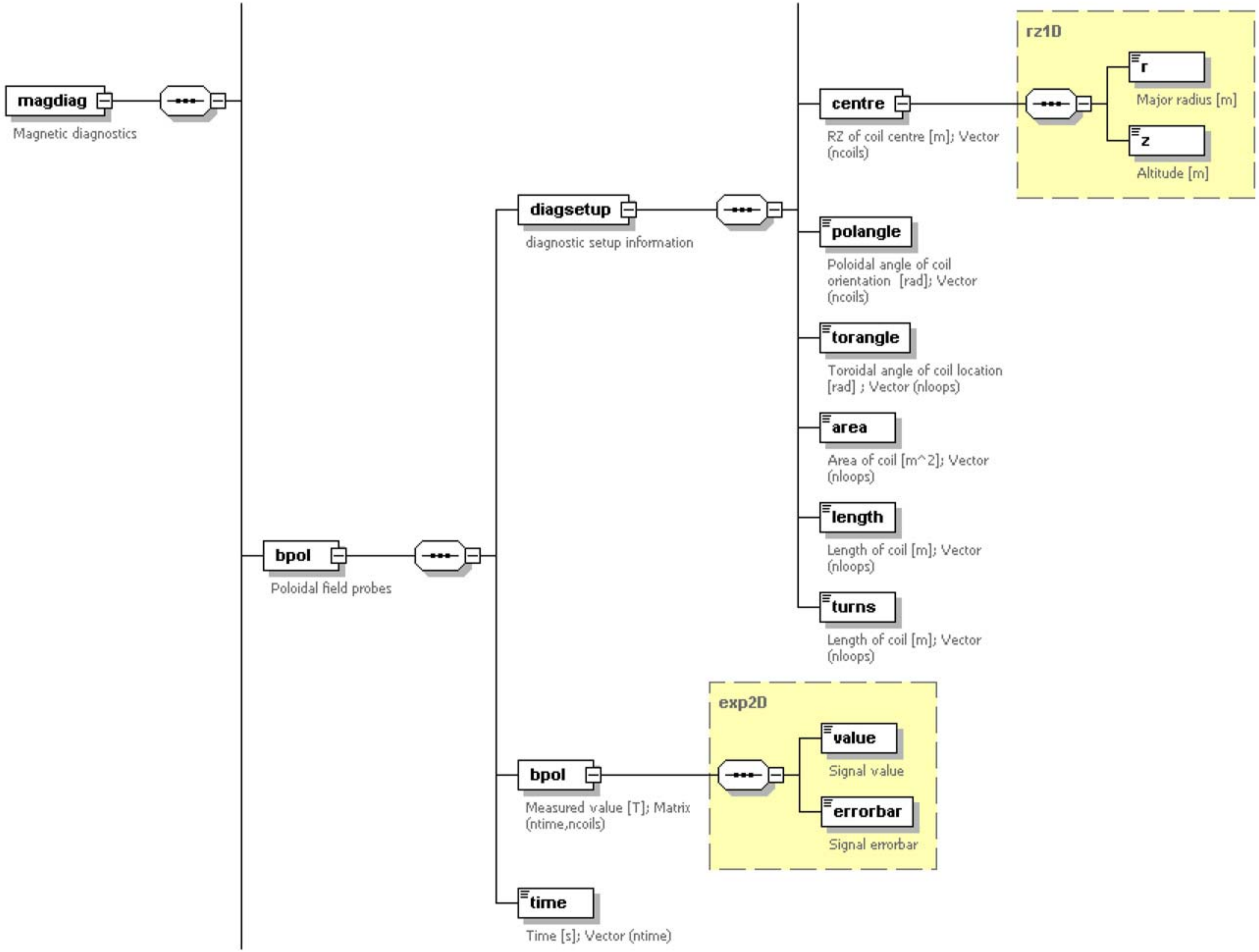
Recent News on Integrate Modeling

- **ITER**: Request for job application (Dec., 2006)
  - **Chief Scientific Officer, Integrated Modelling**: PhD, 15 years
  - Senior Scientific Officer, Transport and Confinement Physics
  - Senior Scientific Officer, Integrated Scenarios
- **US**: **SciDAC**
  - **2005**: New subjects
    - Center for Plasma Edge Simulation (**CPES**)
    - Simulation of Wave Interactions with MHD (**SWIM**)
  - **2006**: Request for new proposal
    - Techniques for **international fusion collaboration**
    - **Integrated software environment** for multi-physics, multi-scale simulations
- **EU**: **ITM-TF**

Integrated Tokamak Modelling TF in EU

- **The Code Platform Project** (CPP):
  - Code integration, End user tools
- **The Data Coordination Project** (DCP):
  - Data structure (XML schemas, ITM database)
  - Qualification, Verification, Data validity, and Validation
- **Five Integrated Modelling Projects** (IMPs)
  - **Equilibrium and linear MHD stability**:
    - Reconstruction, High resolution, Stability, EFIT-ITM
  - **Non-linear MHD and disruptions**: RWM, Sawtooth
  - **Transport code and discharge evolution**:
    - Common interface to transport models and boundaries
  - **Transport processes and micro-stability**: Benchmark
  - **Heating, current drive and fast particles**: Self-consistent

Example of ITM database structure



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

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

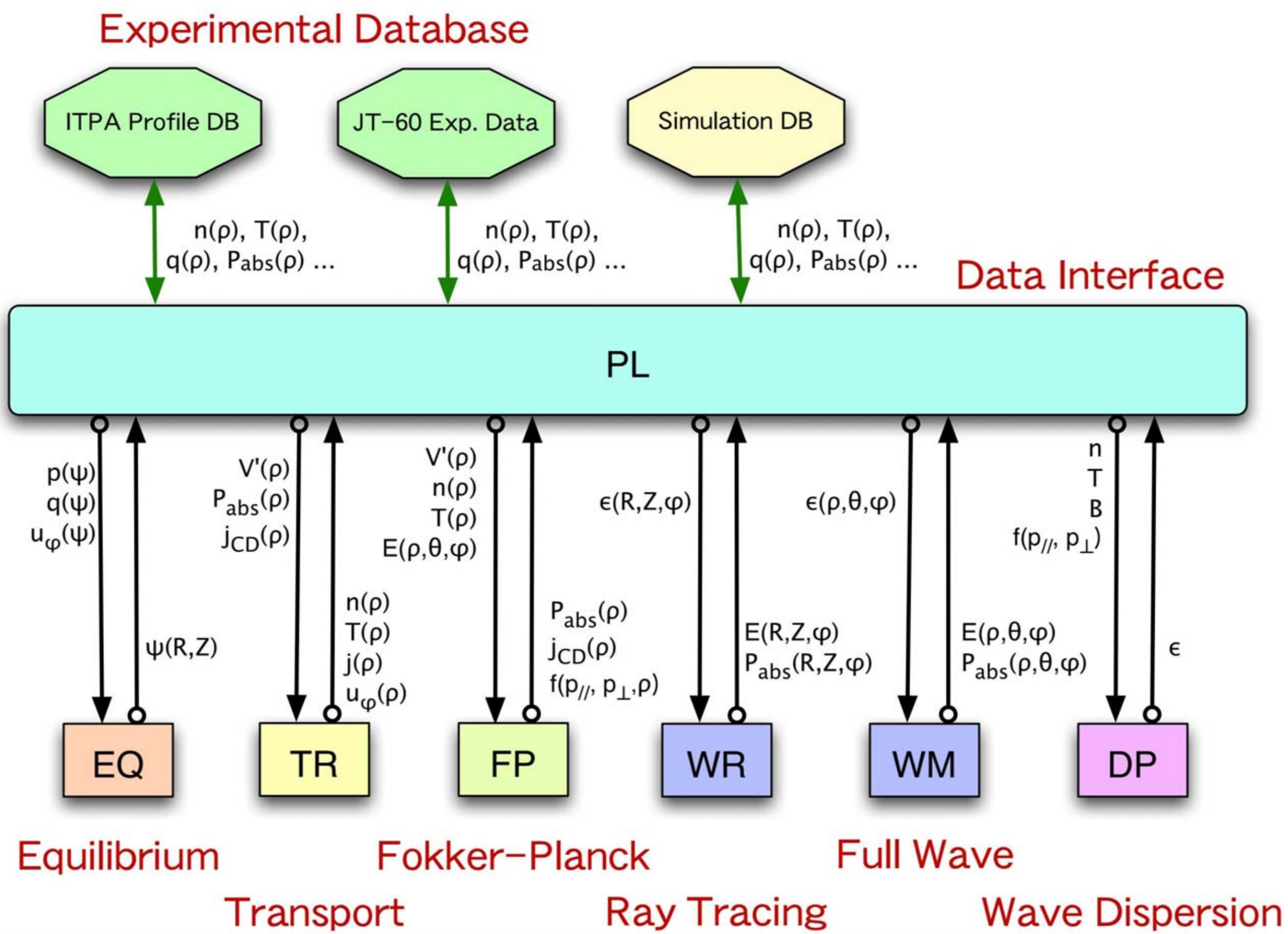
Under Development

TX	Transport analysis including plasma rotation and E_r

Collaboration with TOPICS

EQU	Free boundary equilibrium
NBI	NBI heating

Structure of TASK



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 base**

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	T	Vacuum toroidal mag. field
RKAP	κ		Elongation at boundary
RDLT	δ		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: $V'(\rho)$, $\langle \nabla V \rangle(\rho)$, $\cdots$

2D: g_{ij}, $\cdots$

3D: g_{ij}, $\cdots$

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	$\overleftrightarrow{\epsilon}(\rho, \chi, \zeta)$		Local dielectric tensor

Full wave field data

CE	$\boldsymbol{E}(\rho, \chi, \zeta)$	V/m	Complex wave electric field
CB	$\boldsymbol{B}(\rho, \chi, \zeta)$	$\mathrm{Wb/m}^2$	Complex wave magnetic field

Ray/Beam tracing field data

RRAY	$R(\ell)$	m	R of ray at length ℓ
ZRAY	$Z(\ell)$	m	Z of ray at length ℓ
PRAY	$\phi(\ell)$	rad	ϕ of ray at length ℓ
CERAY	$\boldsymbol{E}(\ell)$	V/m	Wave electric field at length ℓ
PWRAY	$\boldsymbol{P}(\ell)$	W	Wave power at length ℓ
DRAY	$\boldsymbol{d}(\ell)$	m	Beam radius at length ℓ
VRAY	$\boldsymbol{v}(\ell)$	1/m	Beam curvature at length ℓ

Data Exchange Interface

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

	time	`plasmaf%time`
	number of grid	`plasmaf%nrmax`
e.g.	square of grid radius	`plasmaf%s(nr)`
	plasma density	`plasmaf%data(nr)%pn`
	plasma temperature	`plasmaf%data(nr)%pt`

- **Program interface**

	Initialize	`bpsd_init_data(ierr)`
e.g.	**Set data**	`bpsd_set_data('plasmaf',plasmaf,ierr)`
	Get data	`bpsd_get_data('plasmaf',plasmaf,ierr)`

- **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%PARM=TR_PARM
TR_STRUCT%EXEC=TR_EXEC
   ...
BPSX_REGISTER('TR',TR_STRUCT)
```

Example of data structure: plasmaf

```
type bpsd_plasmaf_data
   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 type bpsd_plasmaf_data
type bpsd_plasmaf_type
   real(8) :: time
   integer :: nrmax      ! Number of radial points
   integer :: nsmax      ! Number of particle species
   real(8), dimension(:), allocatable :: s
                         ! (rho^2) : normarized toroidal flux
   real(8), dimension(:), allocatable :: qinv
                         ! 1/q : inverse of safety factor
   type(bpsd_plasmaf_data), dimension(:,:), allocatable :: data
end type bpsd_plasmaf_type
```

Examples of sequence in a module

- **TR_EXEC(dt)**

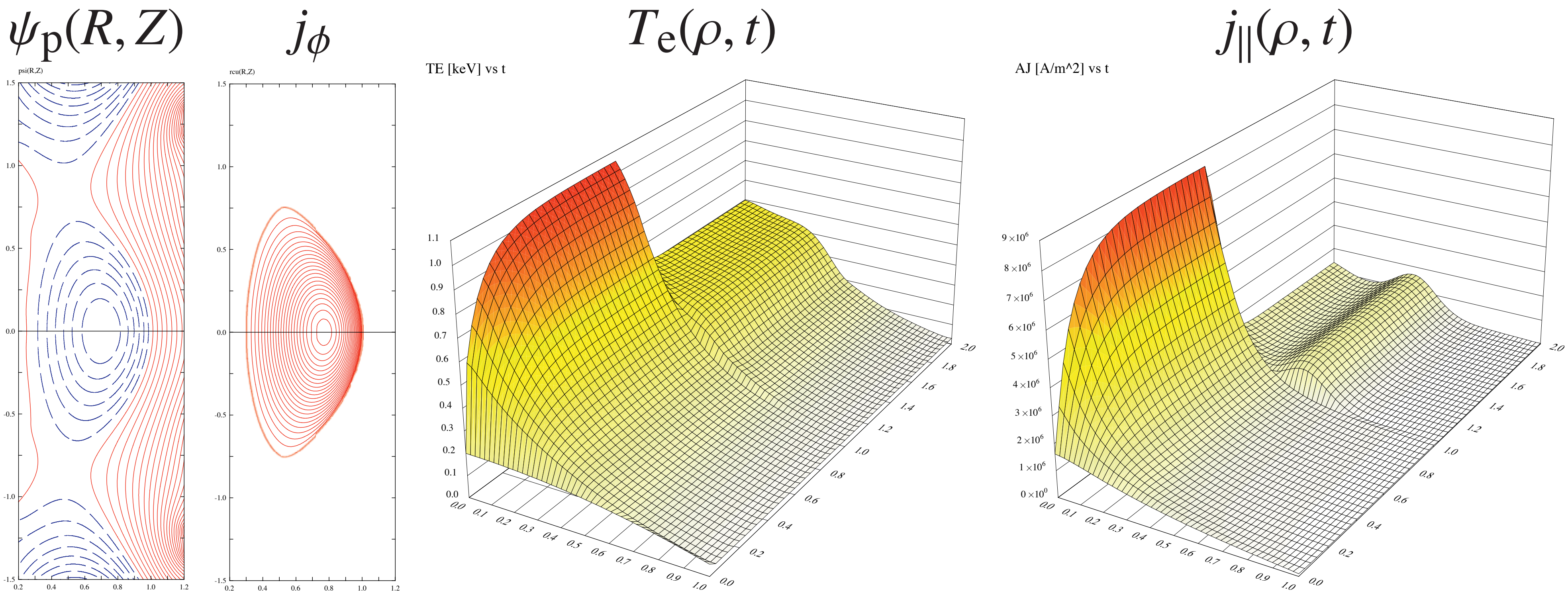
```
call bpsd_get_data('plasmaf',plasmaf,ierr)
call bpsd_get_data('metric1D',metric1D,ierr)
local data <- plasmaf,metric1D
advance time step dt
plasmaf <- local data
call bpsd_set_data('plasmaf',plasmaf,ierr)
```

- **EQ_CALC**

```
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)
```

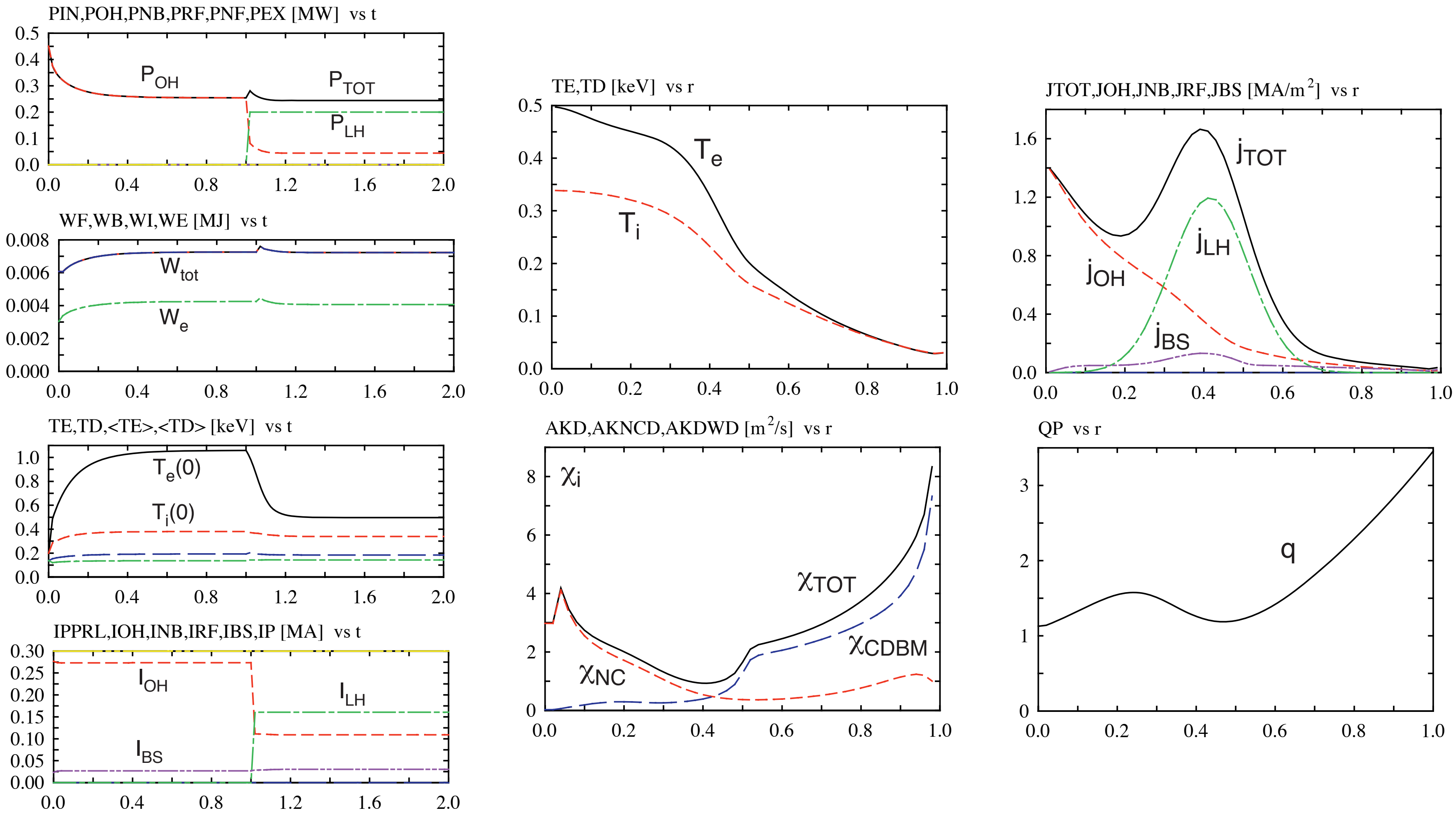
Example: Coupling of TASK/TR and TOPICS/EQU

- **TOPICS/EQU**: Free boundary 2D equilibrium
- **TASK/TR** Diffusive 1D transport (CDBM + Neoclassical)
- **QUEST** parameters:
    - $R = 0.64\,\mathrm{m}$, $a = 036\,\mathrm{m}$, $B = 0.64\,\mathrm{T}$, $I_\mathrm{p} = 300\,\mathrm{kA}$, OH+LHCD



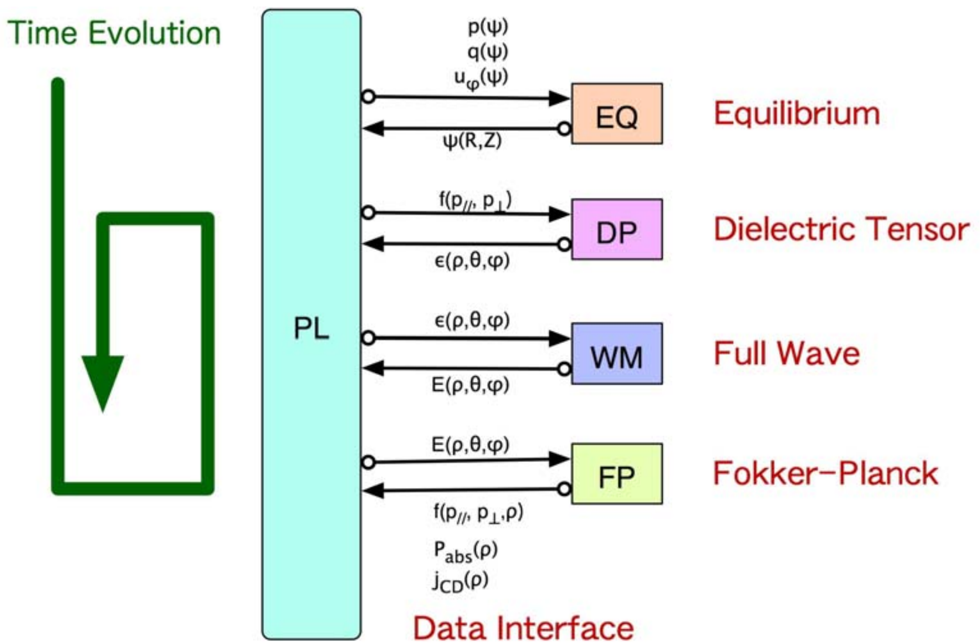
Transport simulation

- **OH + off-axis LHCD**: 200 kW
- **Formation of internal transport barrier** (equilibrium not solved)



Self-Consistent Wave Analysis with Modified $f(v)$

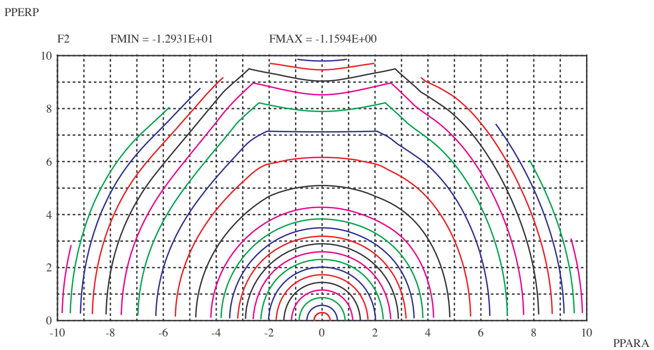
- **Modification of velocity distribution from Maxwellian**
  - Absorption of ICRF waves in the presence of energetic ions
  - Current drive efficiency of LHCD
  - NTM controllability of ECCD (absorption width)
- **Self-consistent wave analysis including modification of $f(v)$**

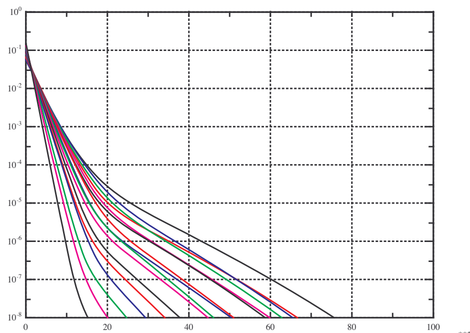


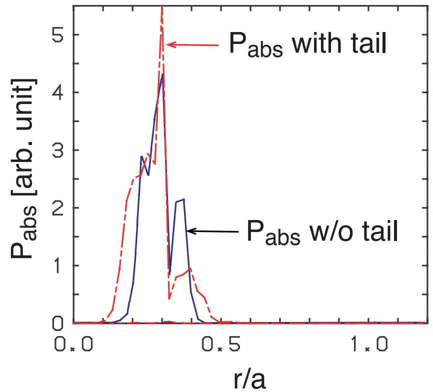
Self-Consistent ICRF Minority Heating Analysis

- **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







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

Future Plan of TASK code

- **Short term**
  - **PL**: BPSI interface to all modules
  - **EQ,TR**: Fortran95 version
  - **FP**: Update for multi species, mpi parallel
  - **WM**: Integral form of dielectric tensor for FLR effects
- **Middle range**
  - **EQ**: Equilibrium evolution like TSC
  - **FP**: Kinetic transport analysis
  - **TR**: Edge plasma model, Impurity, Neutral, MHD stability
  - **EG**: Linear micro instability + Zonal flow effect
- **Long term**
  - **WM**: Particle bounce motion, Kinetic stability analysis
  - **TF**: 2D transport including core and SOL
  - **WB**: Beam propagation

Load map of TASK code

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

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 its influence on the wave propagation and absorption have been obtained.
- We need further continuous development of integrated modeling for comprehensive ITER simulation.