Development of a Novel Integrated Model GOTRESS+ for Predictions and Assessment of JT-60SA Operation Scenarios Including the Pedestal

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Abstract

- GOTRESS can find out an exact steady-state solution using global optimization techniques and robustly deal with stiff transport models.
- A novel integrated model GOTRESS+ with GOTRESS at its core has been developed in collaboration with equilibrium and heating codes.
- GOTRESS+ has been extended to incorporate the in-house EPED1 model exploiting the MHD stability code MARG2D and is now able to predict the plasma profiles over the entire region.
- The ITER-like inductive scenario and the fully current drive high β scenario for JT-60SA have been assessed by GOTRESS+ with CDBM and were found to be feasible with most of the target dimensionless parameters met.

Background

- Operation scenarios are often stipulated by various target parameters such as β_N, the H_H factor and the bootstrap current fraction f_{BS}.
- Self-consistent predictive simulations using an integrated transport model are essential to investigate whether these parameters simultaneously satisfy the specified target values.
- The pedestal governs the plasma performance to large extent.
- The EPED1 model is considered to be the most successful semi-empirical model in predicting pedestal height and width.

GOTRESS / Original GOTRESS+ / EPED1

GOTRESS (Global Optimization version of Transport Equation Stable Solver)

- is an MPI-parallelized novel transport code that finds solutions of the steady-state transport equations using global optimization techniques such as genetic algorithms (GAs) (consult details in [Honda CPC18, PoP19]).
- directly finds out a set of $(T, 1/L_T)$ to satisfy the governing equations.
- does not require numerical differentiation of T to obtain $1/L_T$.
- has an affinity with Deep Learning because GAs produce many data.

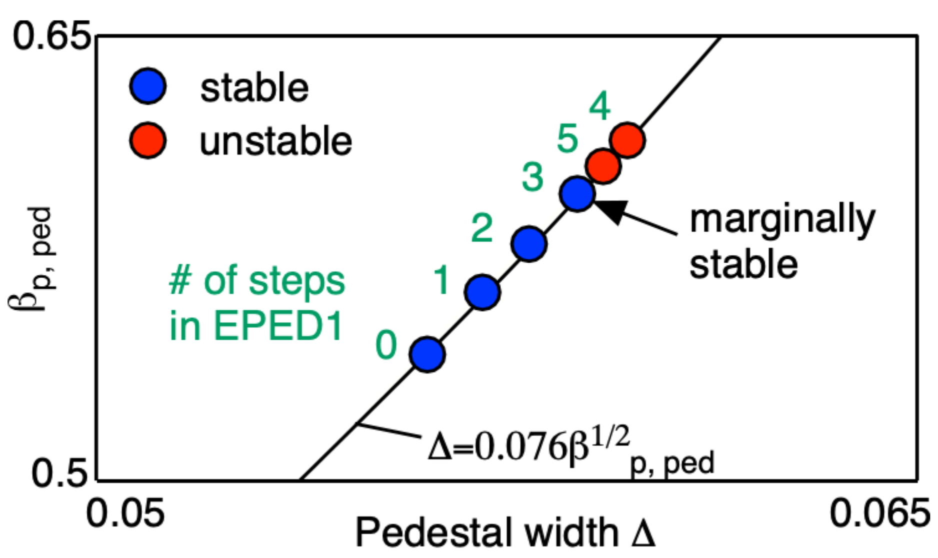
GOTRESS+

- originally consists of **GOTRESS**, the equilibrium and current profile solver **ACCOME**, the orbit-following Monte Carlo code **OFMC** and the ECH code.
- provides us with the consistent steady-state solution of the plasma profiles, the equilibrium and the heating and current drive profiles.
- has given the results same as TOPICS's almost 6 times faster.
- so far has been able to calculate T and $1/L_T$ only inside the pedestal.

We develop our in-house EPED1 model based on the EPED1 model [Snyder PoP09] and incorporate it into GOTRESS+ to calculate profiles over the entire plasma with the pedestal.

Our EPED1 model

- uses the original scaling formula $\Delta=0.076\beta_{p,ped}^{1/2}$ with MARG2D that can evaluate low to high n MHD stability.
- successively increases the pedestal pressure and examines the stability until the plasma becomes unstable.
- gives the final pedestal height at a marginally stable point.



Procedure in our EPED1 model to determine the pedestal height in a marginally stable state

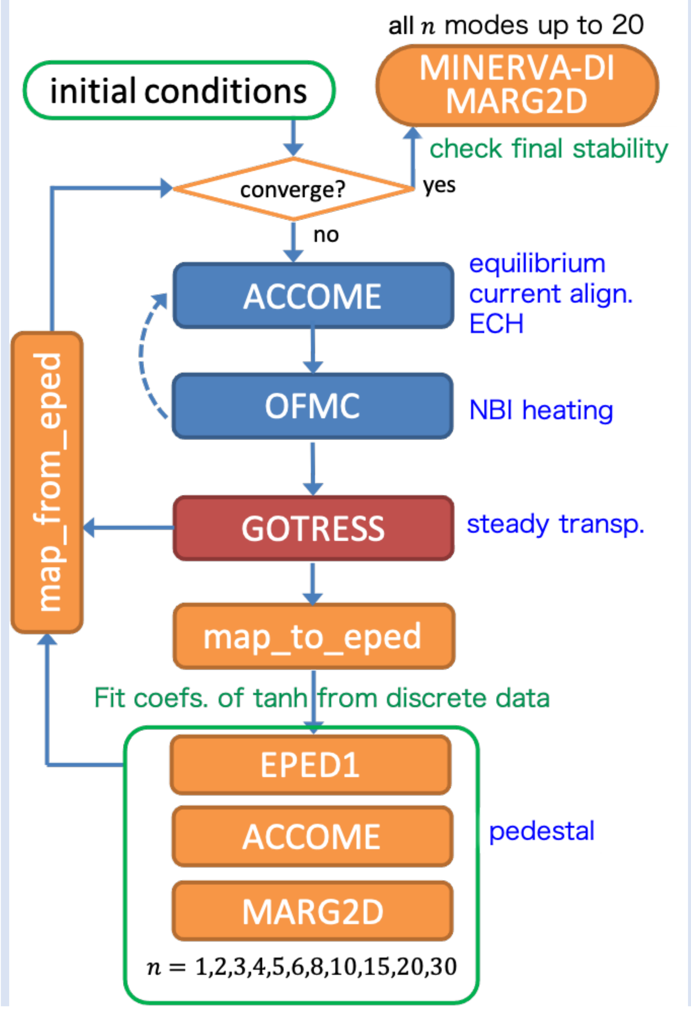
GOTRESS+ incorporating EPED1

Overall

The workflow of GOTRESS+ w/ EPED1, shown in right figure, is regulated by Python scripts and the job scheduler, providing the machine independent execution environment. The converged result will go through MHD stability check by MINERVA-DI or MARG2D.

EPED1 and interface programs in GOTRESS+

- Our EPED1 consists of the EPED1 scaling program, ACCOME and MARG2D.
- EPED1 assumes that profiles are described in tanh function form.
- The "map_to_eped" program works out the coefficients of tanh func. by fitting the discrete profile data from GOTRESS.
- It solves this nonlinear least-squares problem using GAs.

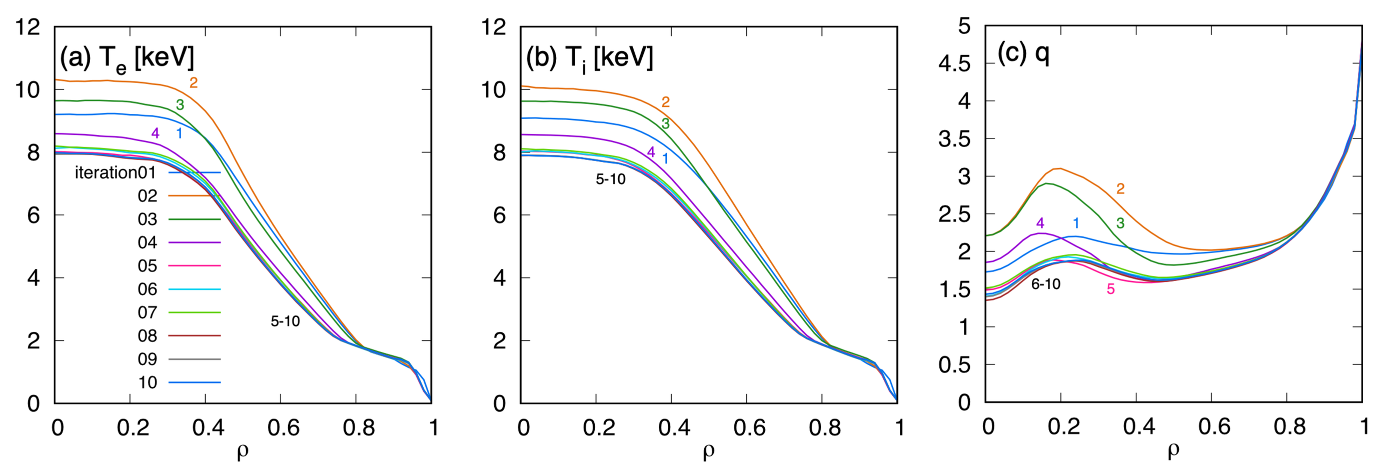


Flowchart of a GOTRESS+ simulation. The workflow in GOTRESS+ is regulated by the Python script and a job scheduler. Whether or not there is a data flow related to the NBCD shown in the dashed arrow from "OFMC" to "ACCOME" depends upon the user's choice.

JT-60SA operation scenario development

ITER-like inductive scenario

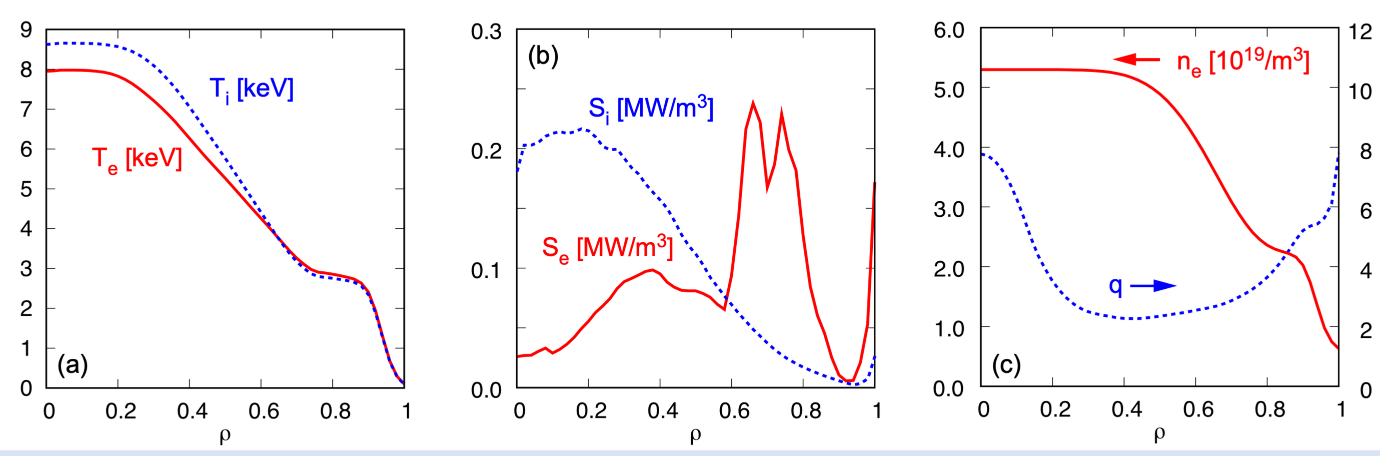
- Single-null equ. with κ=1.81, δ=0.41; I_p/B_T=4.6MA/2.28T, R/a=2.93m/1.14m
- Target values: β_N=2.8, H_H=1.1, f_{BS}=0.3, f_{GW}=0.8 (f_{GW} is given and fixed)
  - ✓ P_{NB}=34 MW (E_{PNB}/E_{NNB}~80keV/500keV) : β_N=2.674, H_H=1.072, f_{BS}=0.23
  - ✓ P_{NB}=34 MW w/ P_{EC}=2 MW (138GHz): β_N=2.929, H_H=1.154, f_{BS}=0.25



GOTRESS+: Converging process of (a) T_e, (b) T_i and (c) q profiles with 138 GHz ECH of 2 MW.

High β_N fully current drive scenario

- Single-null equ. with κ=1.90, δ=0.47; I_p/B_T=2.3MA/1.72T, R/a=2.97m/1.11m
- Target values: β_N=4.3, H_H=1.3, f_{BS}=0.68, f_{GW}=0.85 (f_{GW} is given and fixed)
- Difficult to balance b/w MHD stability and large fraction of BS current.
  - ✓ P_{NB}=16 MW w/ P_{EC}=7 MW (110GHz): β_N=4.33, H_H=1.68, f_{BS}=0.676
  - ✓ Point: E_{NB}=480 keV and the density pedestal being slightly outward



GOTRESS+: Final state of (a) T_e and T_i, (b) S_e and S_i, and (c) n_e and q profiles. S_e and S_i denote ele. and ion heating powers.

Summary and perspectives

- The integrated model GOTRESS+ has been extended to use the in-house EPED1 model implementing MARG2D that can apply to low to high-n modes.
- GOTRESS+ successfully validated the JT-60SA scenarios w/ CDBM almost satisfying the pre-defined target values for dimensionless parameters of β_N, H_H and f_{BS}.
- Use of TGLF for scenario development; Coupling with edge models for B.C.

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