Bringing Anomalous Transport Models to the TRANSP Code as IMAS Components

by

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with

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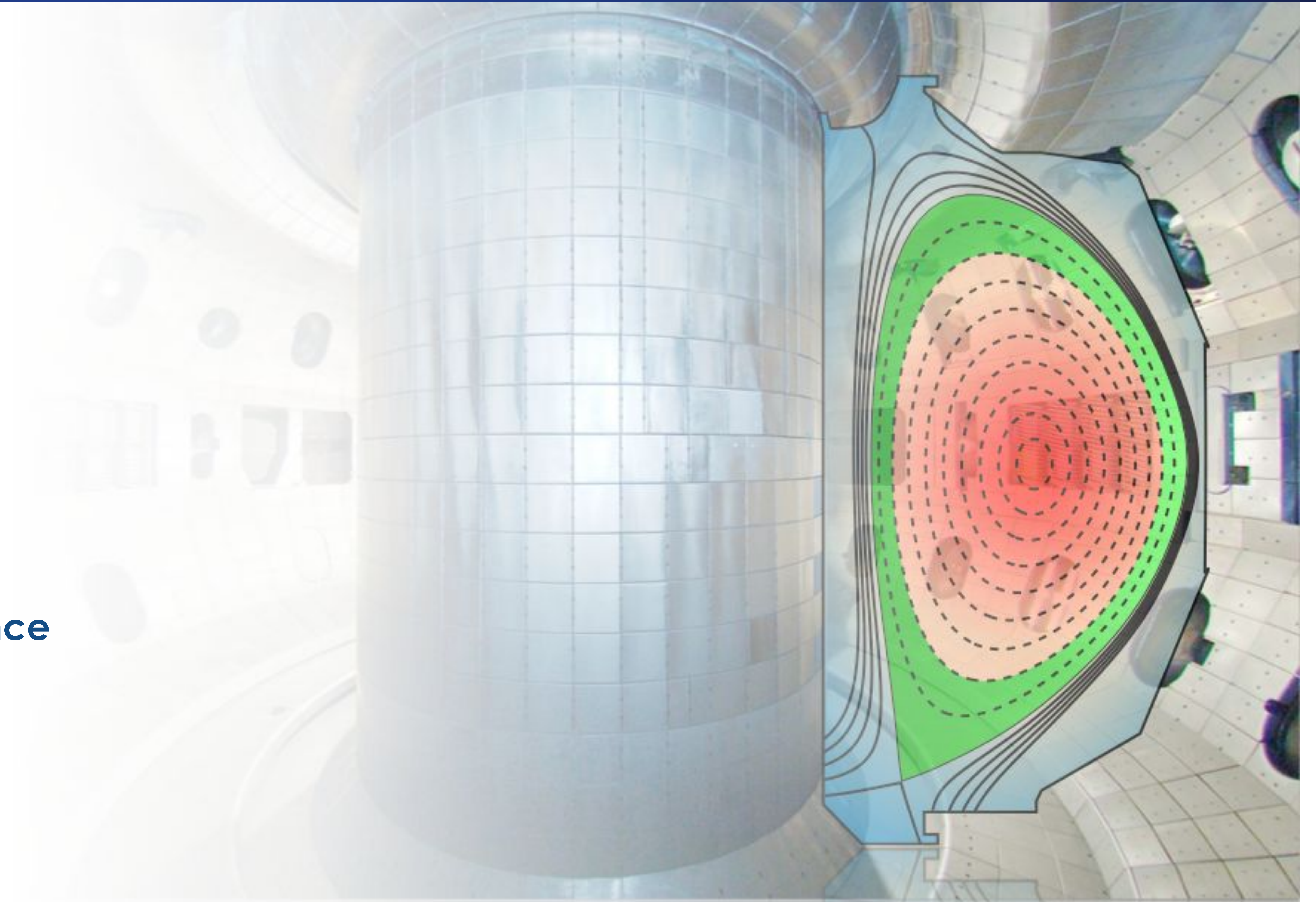

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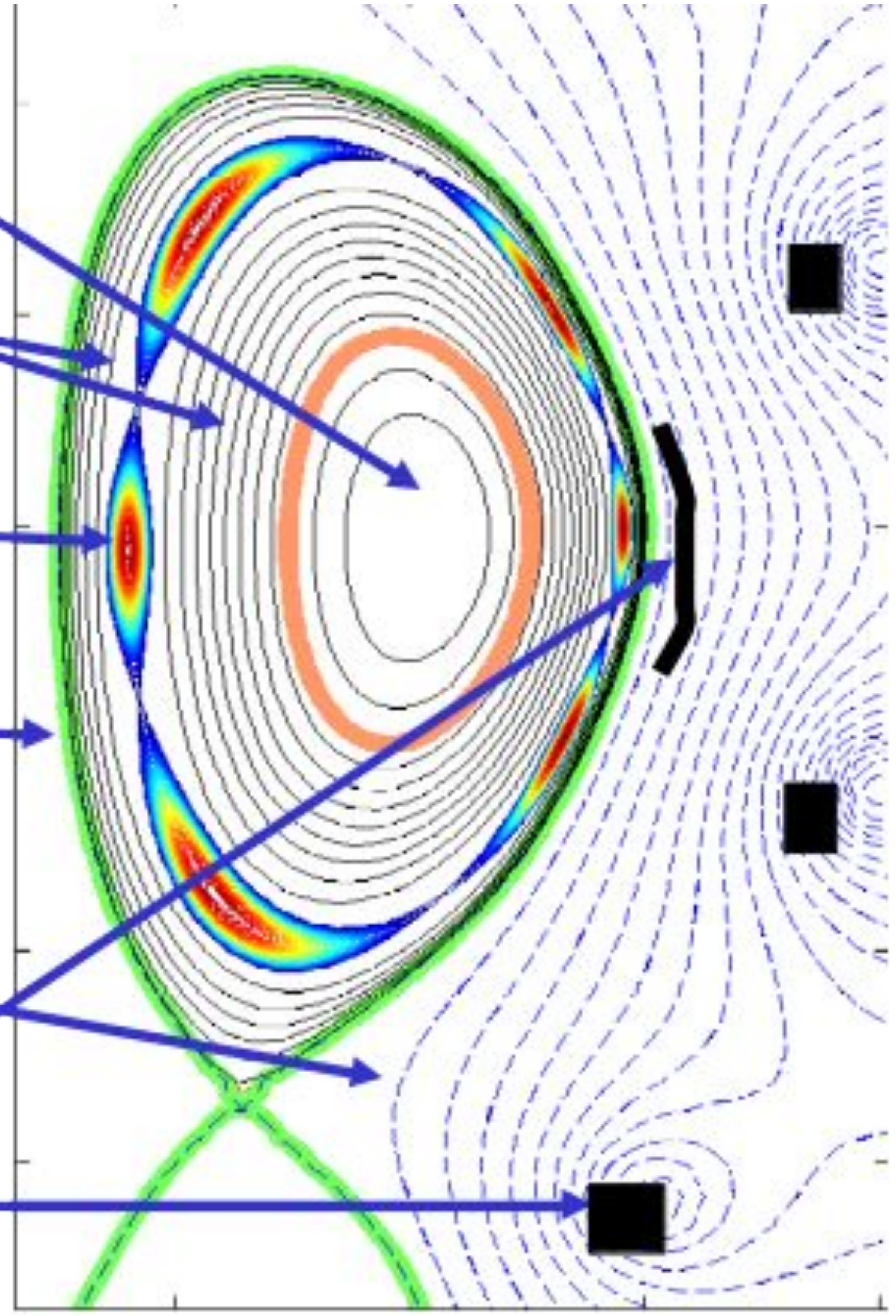
Motivation and Previous Work

- ITER Integrated Modeling and Analysis Suite (IMAS) [F. Imbeaux *et al.* Nucl.Fusion 55 (2015) 123006] establishes standards for fusion data that facilitate coupling of codes and physics modules
  - Number of modules that support IMAS is growing
- TRANSP [J. Ongena *et al.* Trans. of Fusion Technology 33 (1998)181] need to support Interface Data Structures (IDSs) from IMAS in order to
  - Maintain the compatibility with new physics modules
  - Facilitate verification and validation of physics components
  - Improve and standardize visualization capabilities
- Previously, TRANSP input/output was converted to IDSs using post-processing tools
  - Several pre- and post-processing tools have been developed
- In this work, IMAS interface is being implemented for selected modules inside TRANSP

TRANSP is an integrated modeling code

- Sawtooth Region ($q < 1$)
- Core Confinement Region
- Magnetic Islands
- Edge Pedestal Region
- Scrape-off Layer
- Vacuum/Wall/ Conductors/Antenna



Core & Edge Transport

Plasma Turbulence

Large Scale Instabilities

MHD Equilibrium

Heating & Current Drive

Atomic Physics

Radiative Transport

Energetic Particles

Direct interface to IDSs is being implemented for anomalous transport models

- **In future, the interface is intended to replace the existing PlasmaState interface**
- **Interface to the Multi-Mode Model (MMM) v 8.2 [T. Rafiq *et al*., Phys. Plasmas 20 (2013) 032506] for anomalous transport model is selected to test the new approach**
  - **MMM model is removed from TRANSP and re-implemented as external stand-alone library with independent input**
  - **Interface to IDSs is implemented in MMM stand-alone program**
    - `core_profiles` **and** `equilibrium` **IDSs used for input, and** `core_transport` **and** `gyrokinetics` **IDSs for output**
    - **Model specific input is being converted to XML format and is converted to be a part of IDSs**

Multi-Mode Anomalous Transport Model

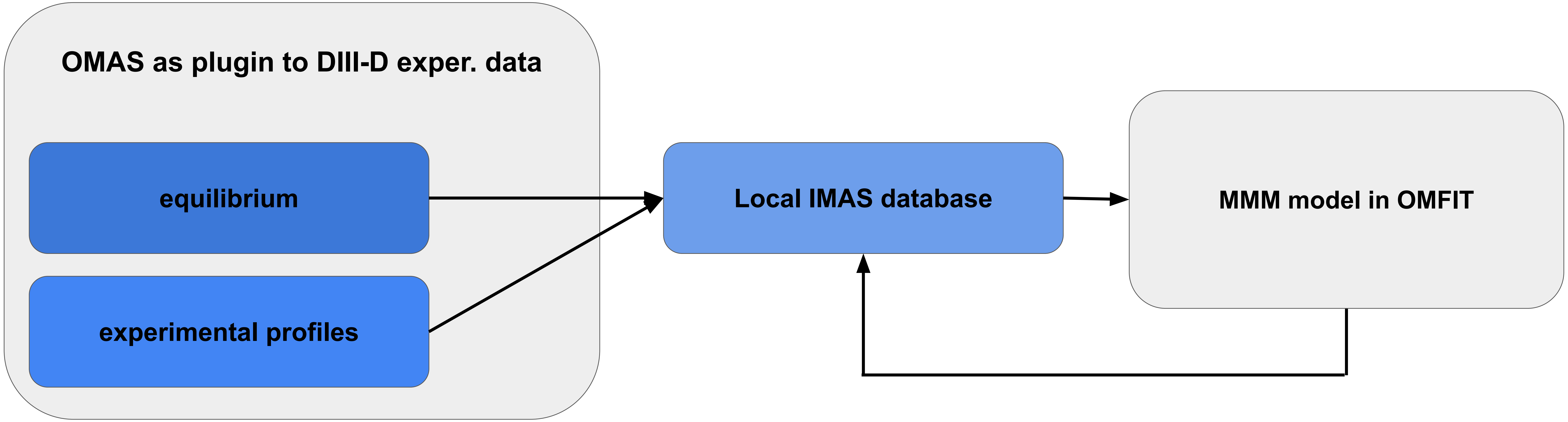
ITG/TEM, DRIBM and MTM components in MMM v8.2 transport model

- **Weiland Model for ITG/TEM: [J. Weiland, Springer (2012); T. Rafiq Phys. Plasmas (2012)]**
  – Transport driven by toroidal and slab ITG, TEM, and MHD modes based on a fluid description
  – Includes effects of $E \times B$ shear, Shafranov-shift stabilization, finite beta, impurity dilution, diffusion and radial convective pinch of toroidal and poloidal angular momentum
  – Quasi-linear estimates are used for computation of all the transport coefficients
- **ETG Model:**
  – Based on the Horton analytical model with empirical corrections and threshold derived from gyro-kinetic simulations
- **DRIBM Model: [T. Rafiq *et al.*, Phys. Plasmas 17, 082511 (2010)]**
  – Computes transport driven by gradients, electron inertial, and inductive effects
  – Mode stability threshold depends on the collision frequency and the density and temperature gradients
- **MTM Model: [T. Rafiq *et al.*, Physics of Plasmas 23, 062507 (2016)]**
  – Derived from gyrokinetic equation with collisions, nonlinear fluid equations of electron momentum, electron density, Maxwell equations, Ampere's law and quasi-neutrality
  – Electron thermal diffusivity is calculated from magnetic field fluctuation amplitude
  – In low-beta plasma, MTM can be still driven because of electrostatic contributions

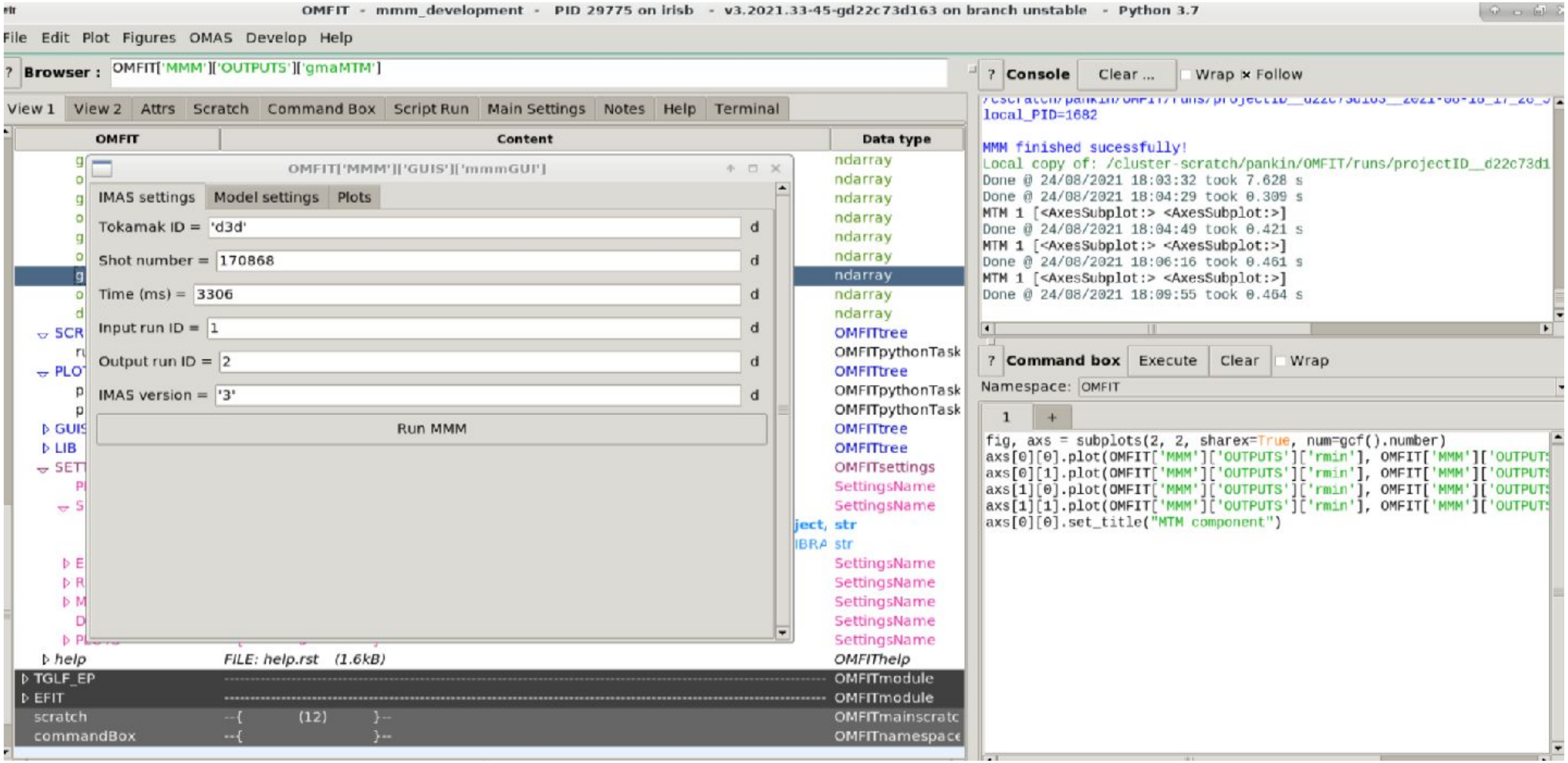
In `core_transport` IDS, output is provided for MMM model and all four components

For the verification, the new model is implemented as a OMFIT component

- **Using OMAS interface in OMFIT [O. Meneghini *et al*. Nuclear Fusion 55 (2015) 083008], the model can access the DIII-D experimental database**



New OMFIT module for MMM stability analysis is being developed



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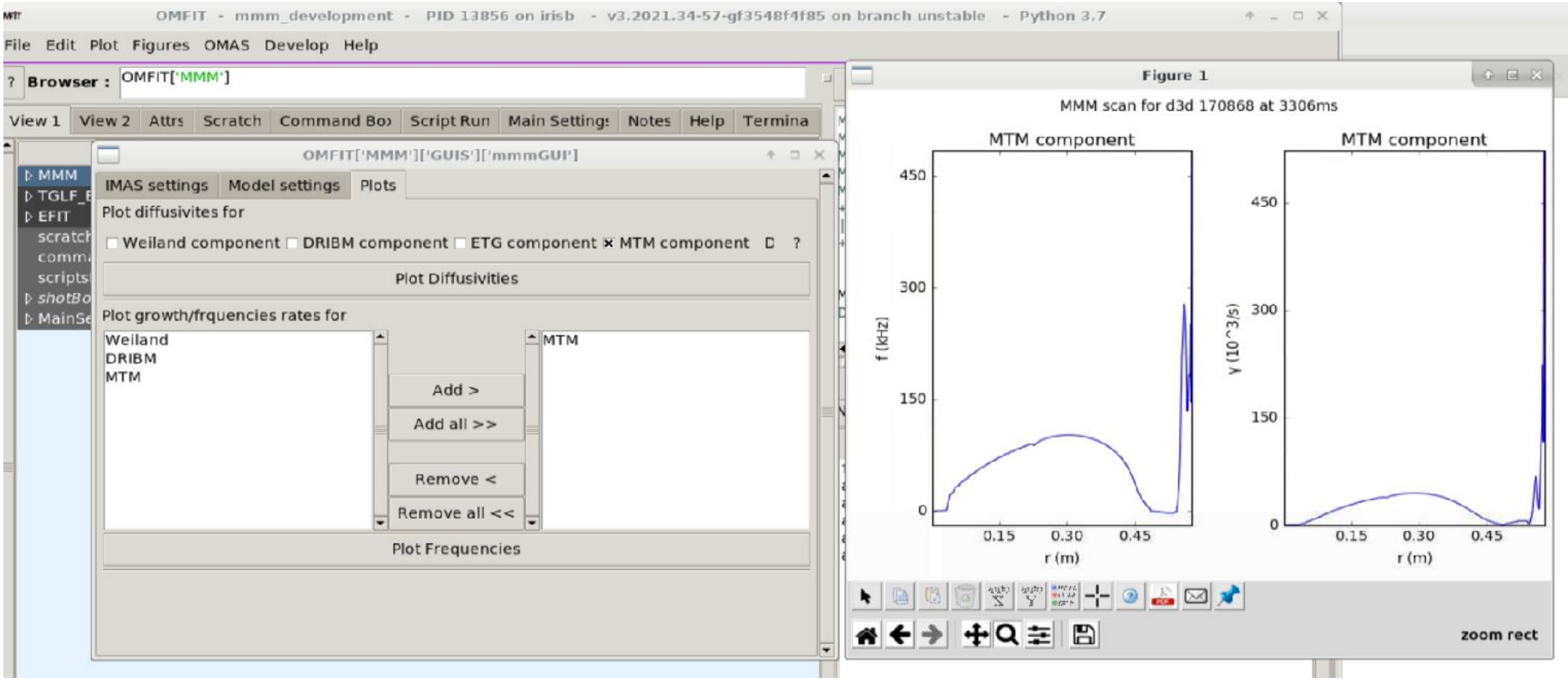
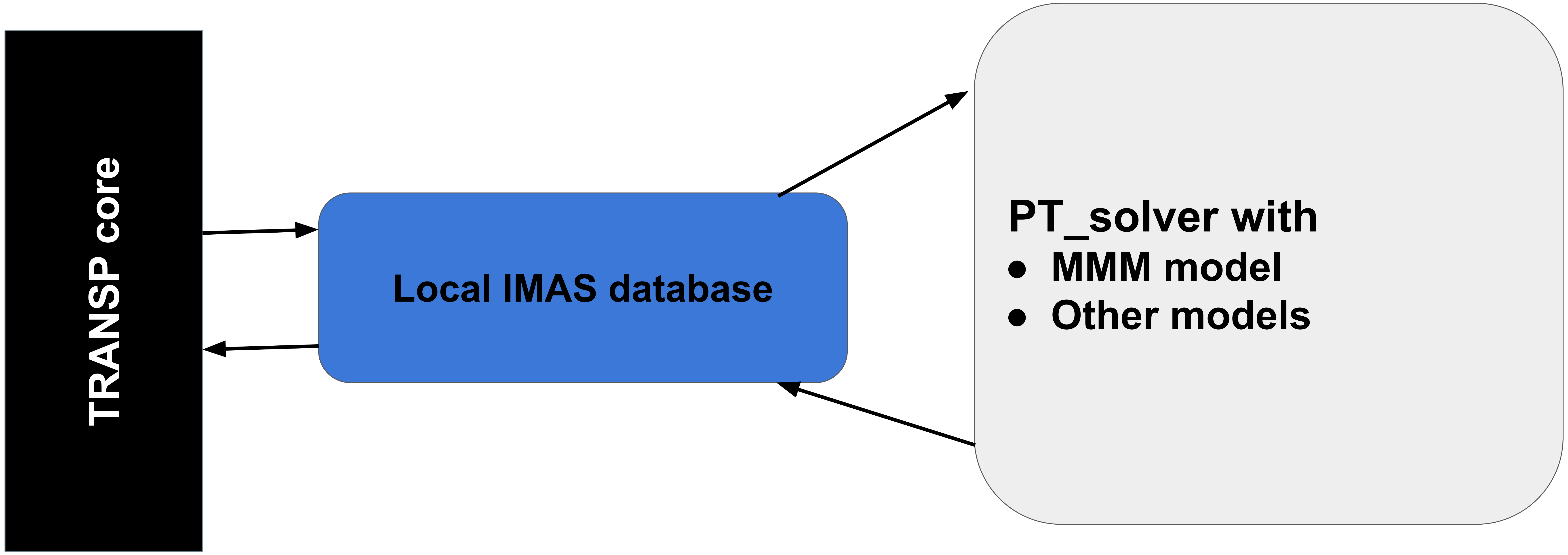


TRANSP uses the same version of MMM as in OMFIT

Existing PlasmaState is being replaced with several IDSs

- Currently relies on MDSPlus
- HDF5 and memory-to-memory backends are being tested



The new interface will facilitate

- Implementation of new transport modules in TRANSP
- Development of unit tests for Continuous integration (CI)
- Cross-verification between different modules

Reduced MTM model is based on a unified fluid-kinetic approach

The MTM modes are

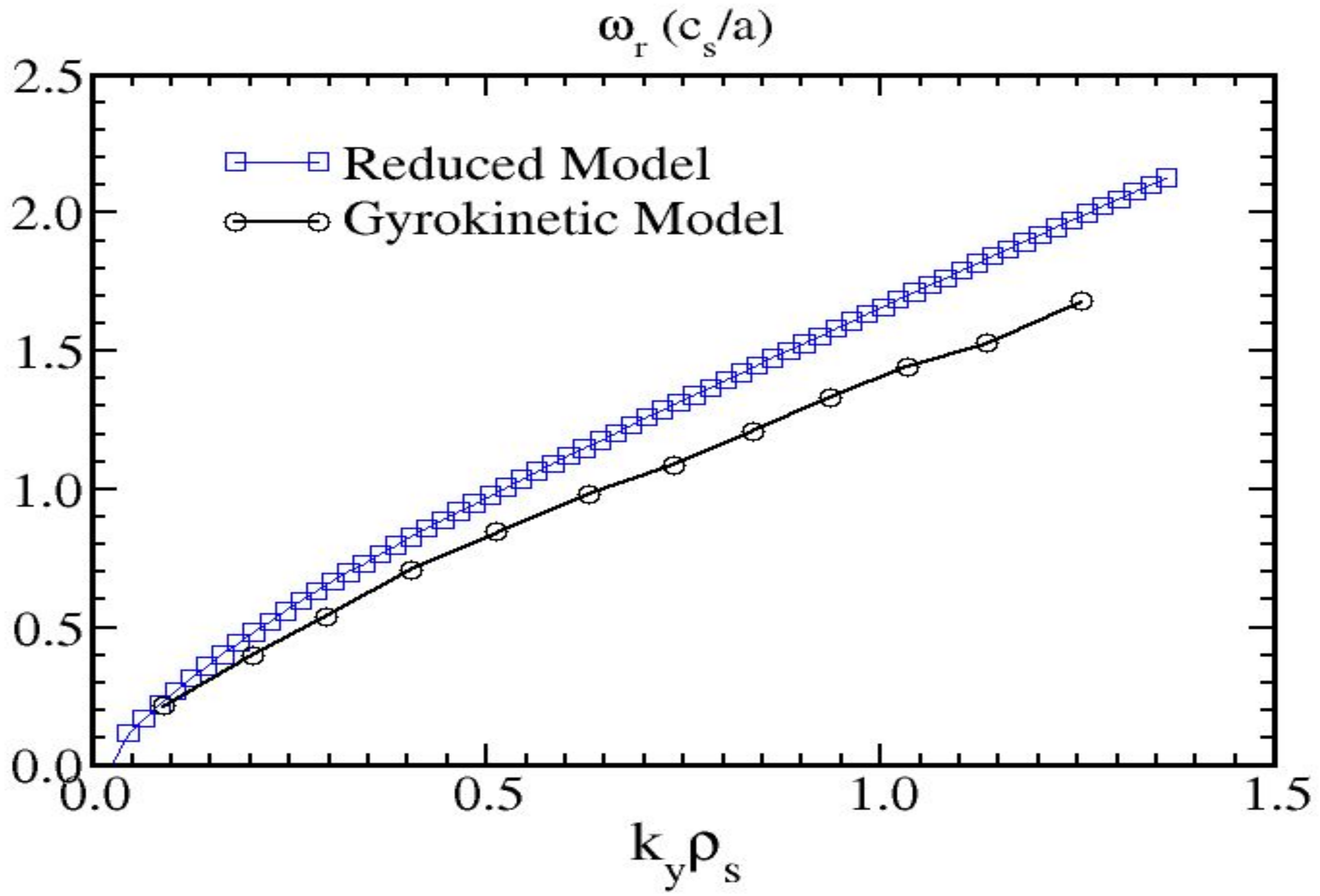
- Ion scale electromagnetic instabilities
- Driven mostly by electron temperature gradients and collisionality
- Propagate in electron diamagnetic drift direction
- Mode structure is extended along magnetic field lines
- Nonlinear MTM produces magnetic islands that saturate by transferring energy to stable short wavelength modes

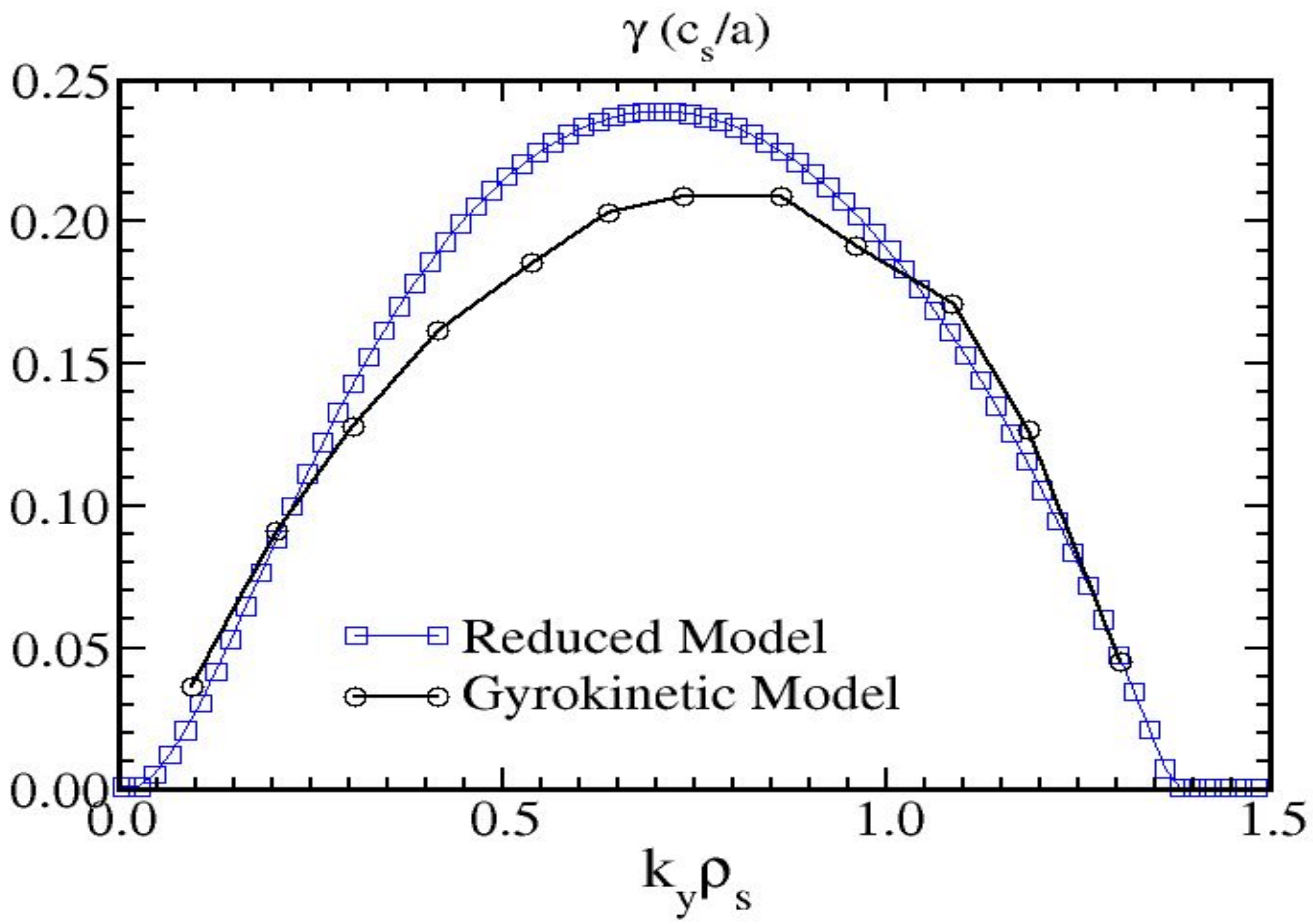
The model takes into account

- Temperature and density gradients
- Collisionality
- Fluctuations of electrostatic ($\delta\varphi$) and magnetic $\delta A_{||}$ potential
- Magnetic curvature
- Electron inertia

Growth rates and frequencies in GYRO and reduced model agree within 25%

Plasma parameters for the NSTX Discharge 120968 used for comparison [T. Rafiq, PoP 2021]





MTM linear growthrate and real frequency as a function of $k_y\rho_s$ is compared with gyrokinetic code GYRO MTM linear growthrate and real frequency [W . Guttenfelder PoP (2012)]

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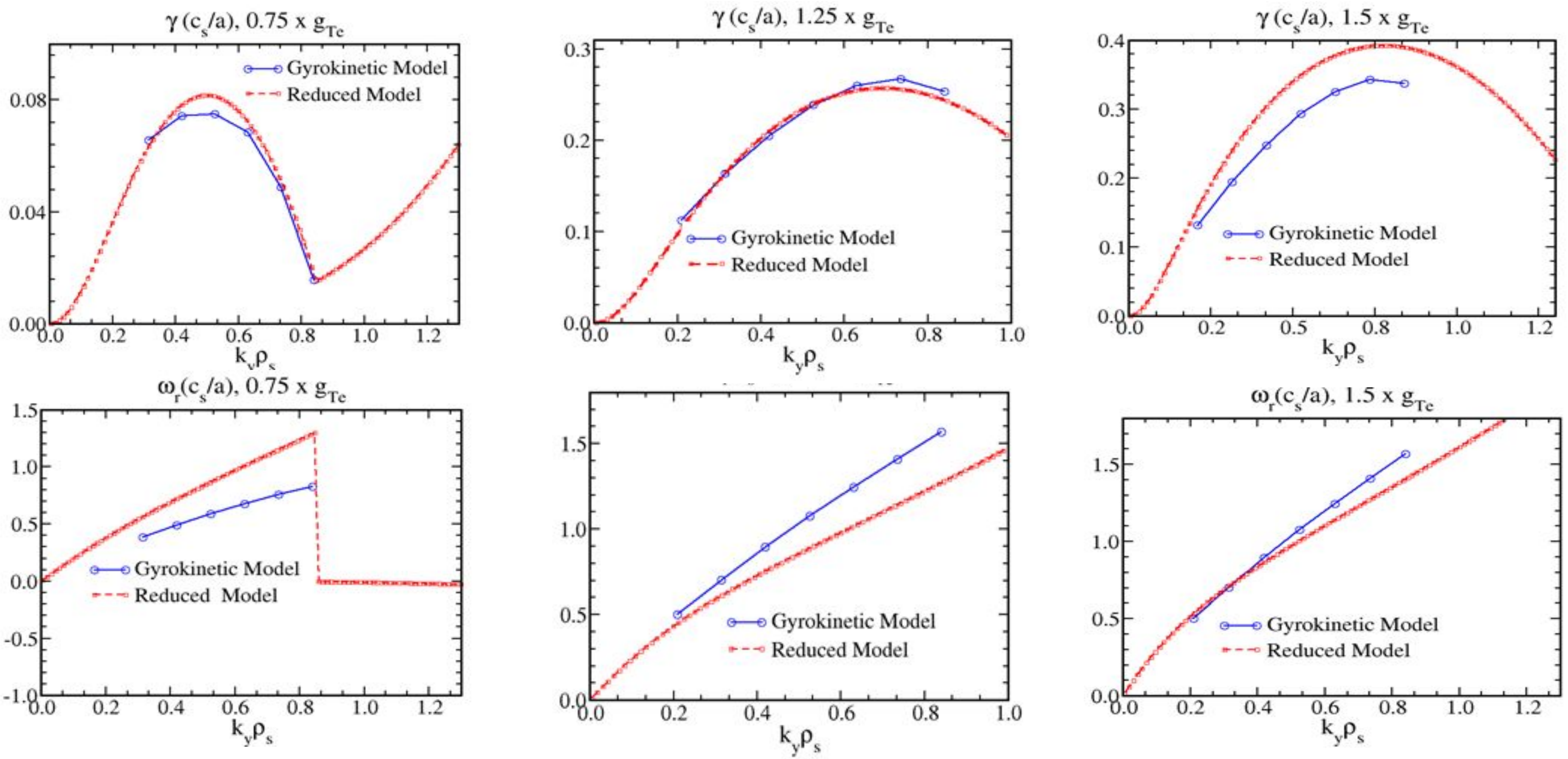
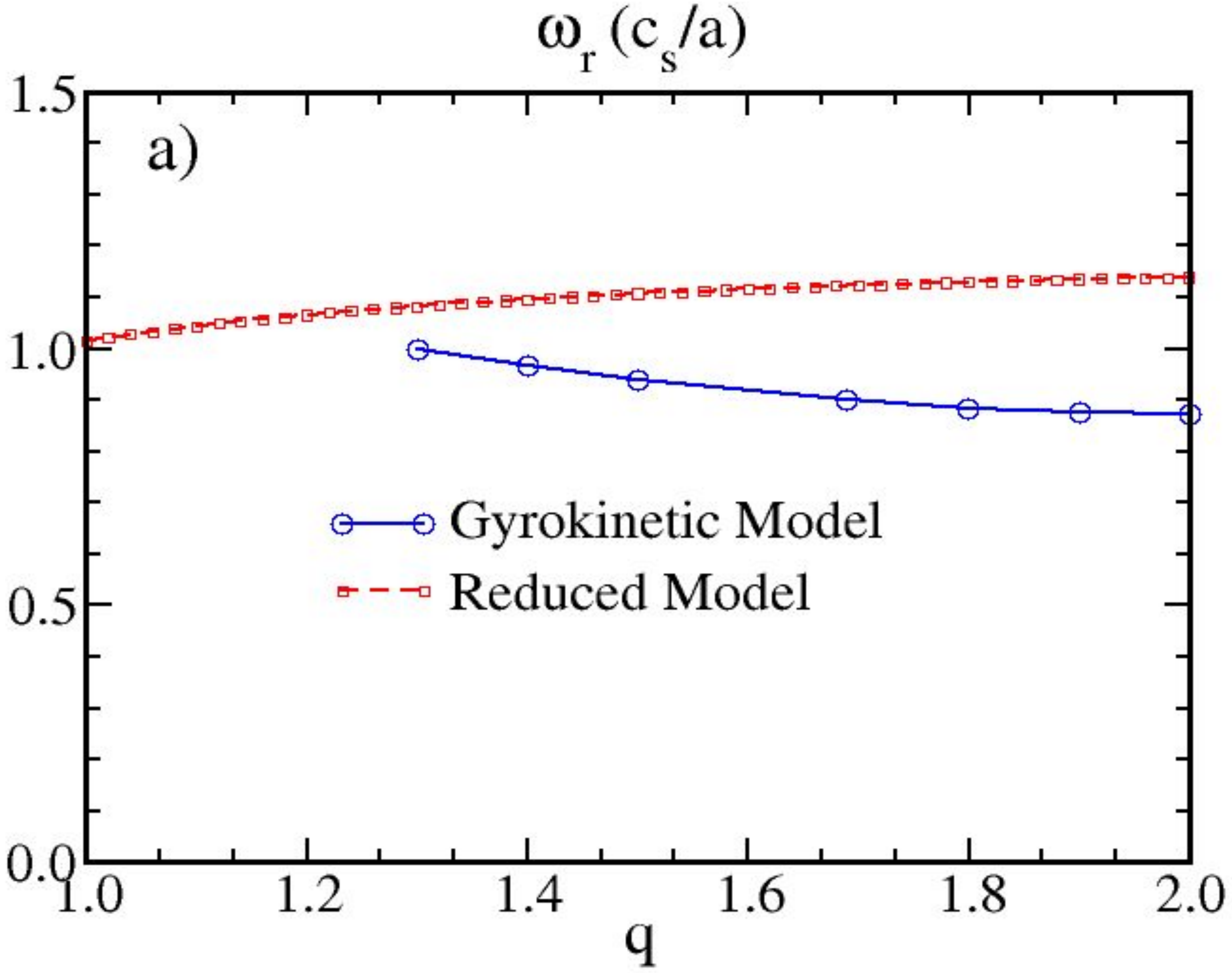
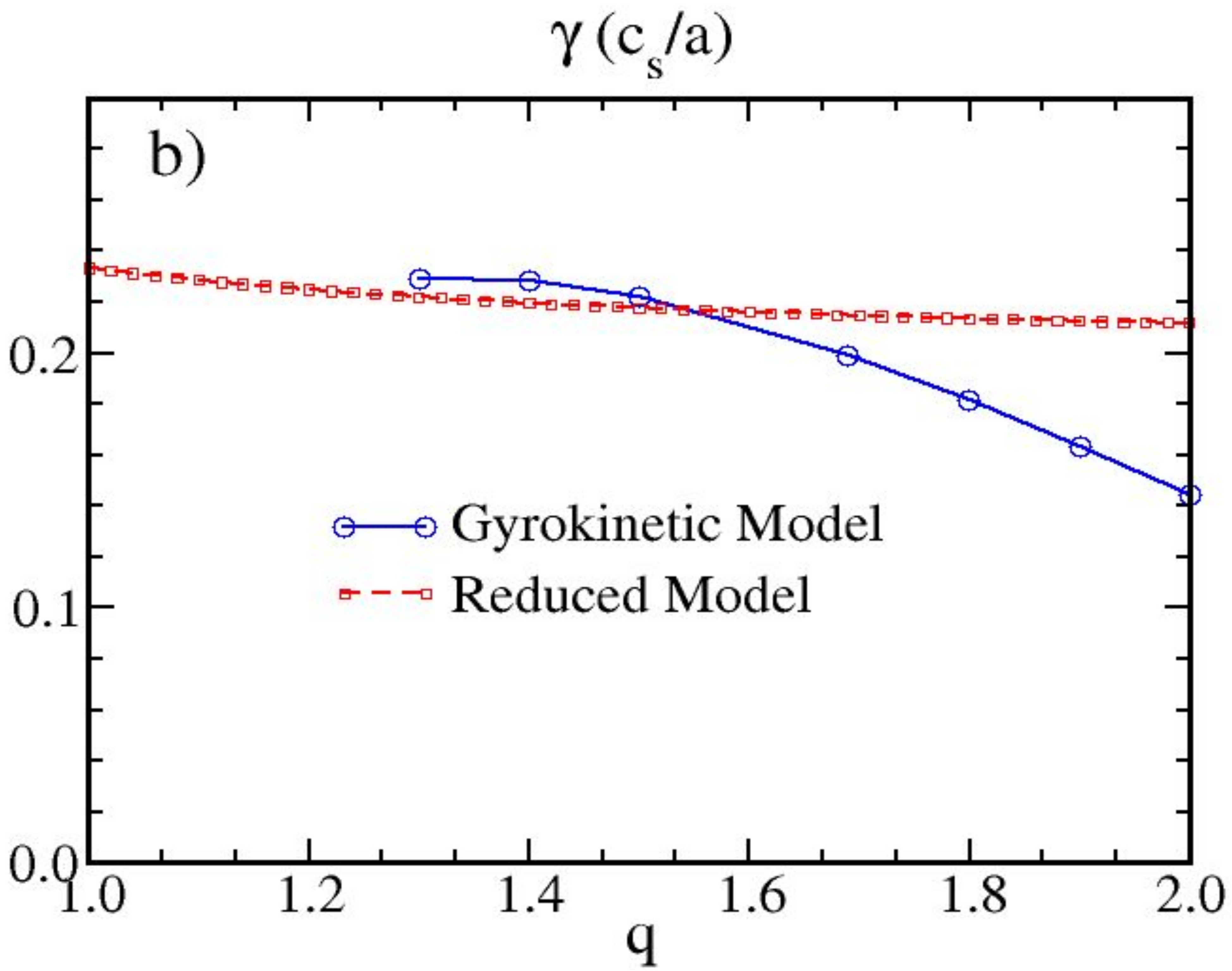


Magnetic-q: Comparison between reduced model and Gyrokinetic MTM linear growthrate and frequency

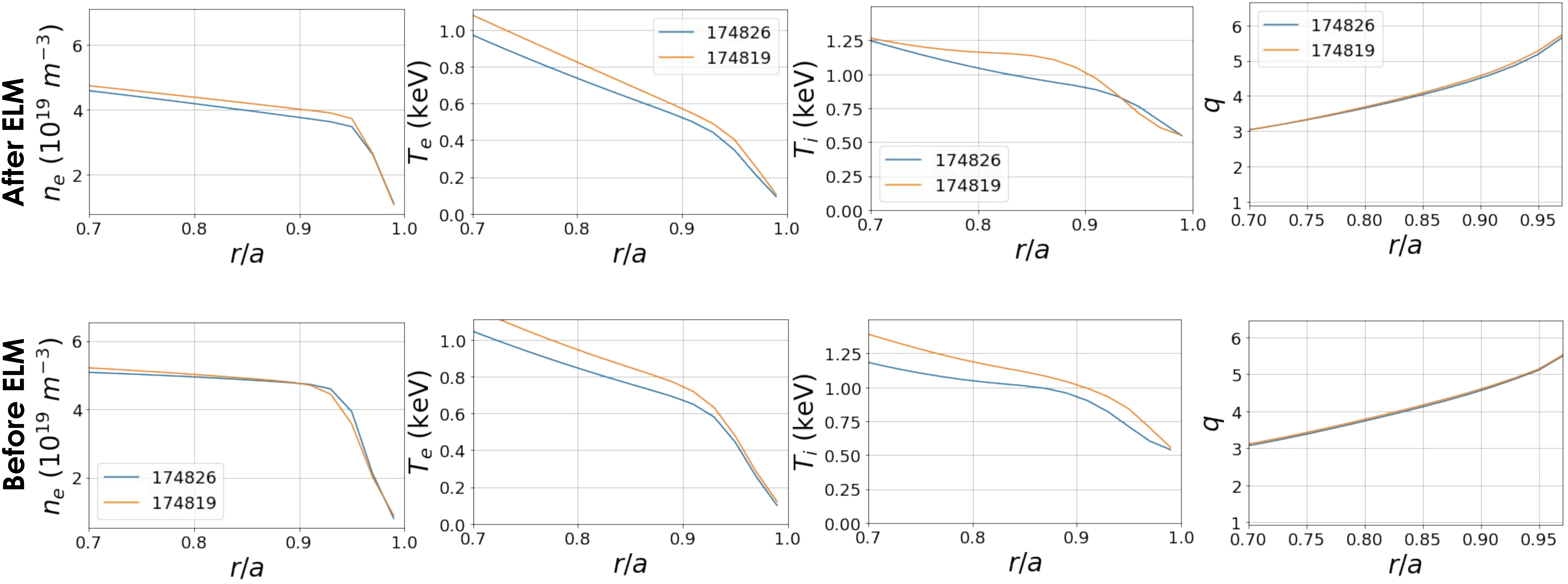




- **Magnitude of real frequency and growthrate in reduced and gyrokinetic models are not very different, but decreasing of growthrate for larger values of magnetic *q* in the gyrokinetic model results is not captured by the reduced model**
  - **Simple estimation of $k_{\|}$, which does not depend on toroidal geometry, might be a reason of not capturing the decreasing trend of γ for large values of magnetic *q***

Pedestal buildup in high and low torque DIII-D discharges are considered

We consider low and high torque cases [A. Diallo APS DPP 2020]



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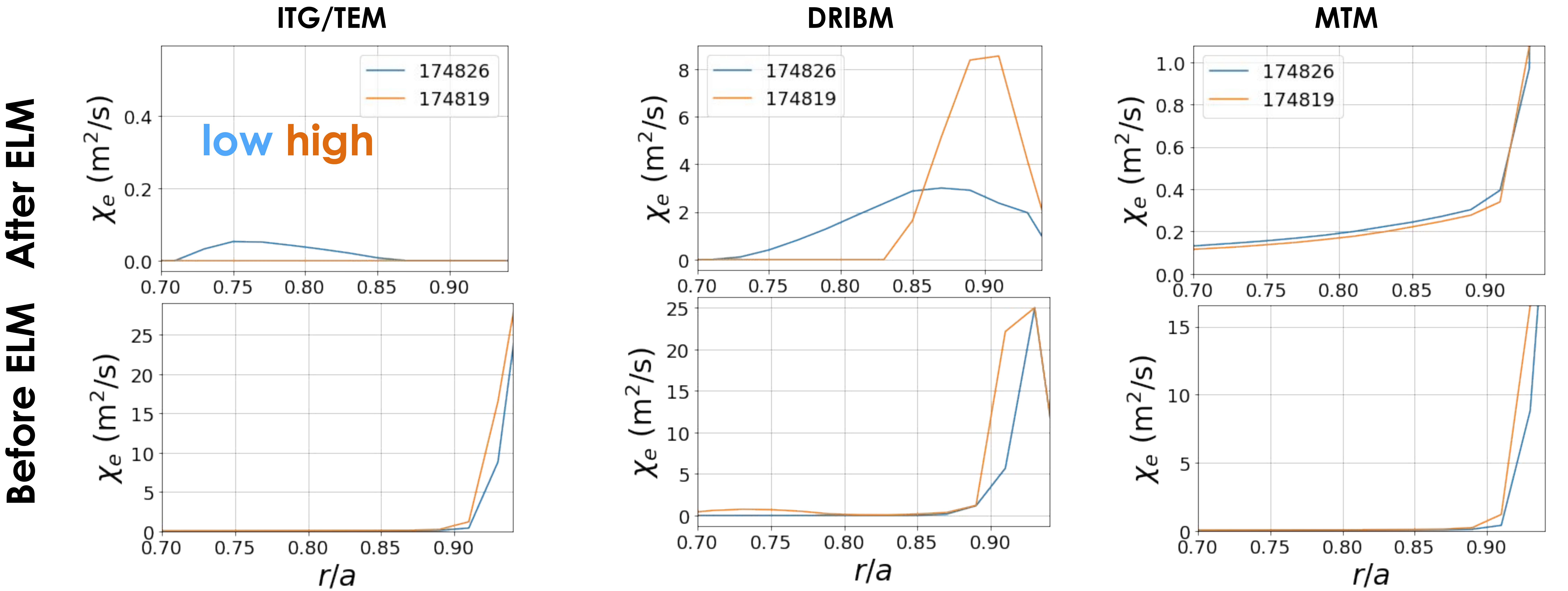
low an high torque cases

Stability of different modes contributing to electron thermal anomalous transport is studied using MMM in TRANSP



Based on mode frequencies

- ITG contributes in core and pedestal top
- TEM contributes inside pedestal
- Stronger TEM contribution discharge with higher torque

Some MHD modes are unstable in DRIBM model
These modes contributes near the pedestal top

MTM modes are unstable inside the pedestal

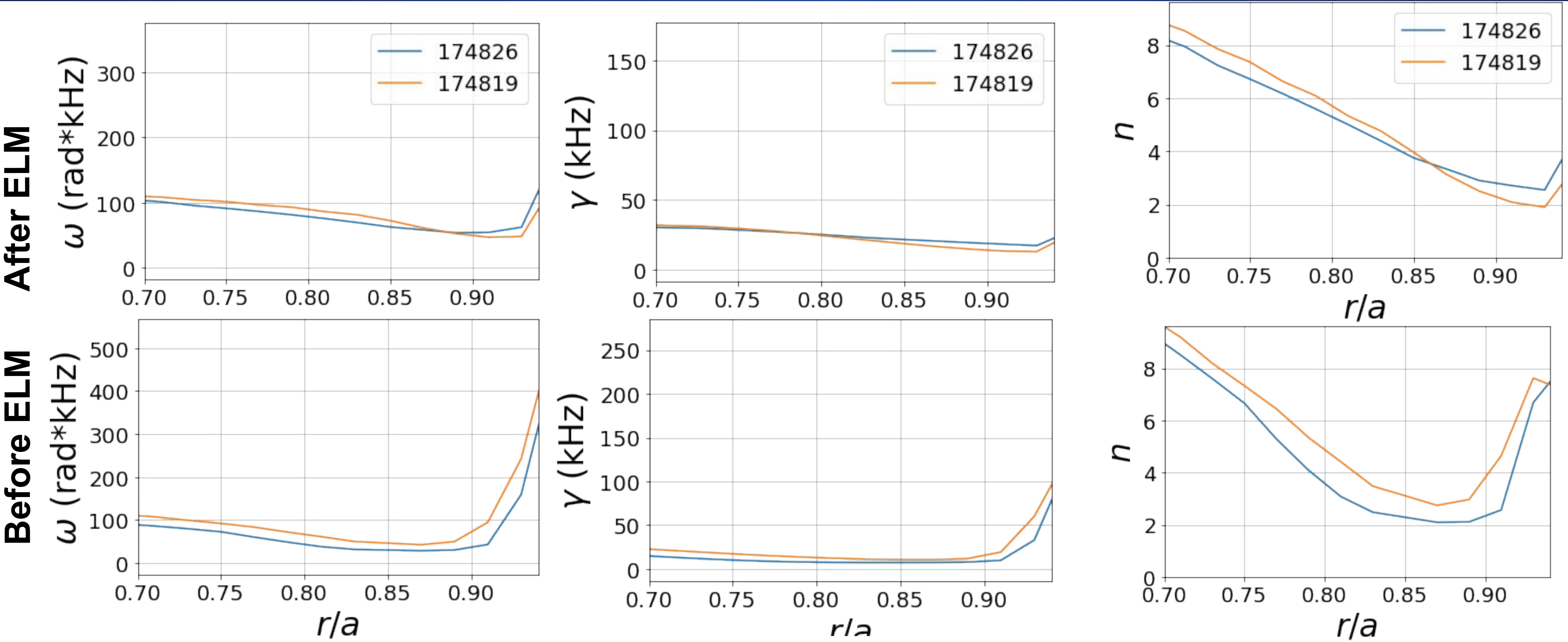
- Profiles are not evolve in these simulations
- Due to different model stiffness, diffusivities for different modes cannot be compared
- However, the diffusivities for the same mode under different plasma conditions can be compared

MTM contribution to the electron thermal transport

Frequencies of MTMs in discharge with high torque is found higher than the MTMs frequencies in discharge with low torque

- $k_y \rho_s$ for the most unstable MTM modes is found larger for discharge with higher torque for profiles before ELM crash
- This corresponds to larger toroidal mode numbers for DIII-D discharge 174819 before ELM crash
- Toroidal modes associated with MTM unstable modes are lower after ELM crash and higher before ELM crash

MTM contribution to the electron thermal transport



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Summary

TRANSP code is currently going through significant modernizations

- Modules are being updated and moved as outside modules
- PlasmaState and IMAS interfaces are currently co-exist in TRANSP code
- In future, IMAS will replace PlasmaState

Multi-Mode Model for anomalous transport has been selected to test the IMAS interface

- Input and output to MMM is implemented using several IDSs
- To test the access to experimental data, the updated model is implemented in OMFIT

MMM in TRANSP code is used for stability analysis of instabilities that can drive the anomalous transport in the plasma edge of DIII-D discharges

- It is shown that MTMs modes can be unstable in the plasma edge
- These electromagnetic modes can be driven through electrostatic contributions even for moderate values of β_e
- For the discharges studied here, TEM mode can contribute to the anomalous transport as well

There are several other ongoing TRANSP projects that involve IMAS as an interface between modules