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A Comprehensive Theory-Based Transport Model* TH-C

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A new theory based transport model called trapped-gyroLandau-fluid (TGLF) has been developed [1]. This new model is physically comprehensive with trapping, collisions, finite beta, unrestricted aspect ratio and general toroidal geometry. Among the new physical regimes accessible to TGLF are low aspect ratio spherical tori. Both the high trapped fraction and strong shaping of magnetic flux surfaces are included. The TGLF model is also valid close to the magnetic separatrix where the magnetic shear is strong. The model is built using a theory-based philosophy. The model is designed to fit exact gyrokinetic linear stability calculations and nonlinear turbulence simulations. No fitting to experiment is done so comparing the model to experiment is a true test of the theory. The TGLF model is a much more accurate fit to gyrokinetic than its predecessor GLF23 [2].

The transport model GLF23 has demonstrated that the core temperature profiles of L-mode and H-mode regimes in tokamaks are well predicted by the thermal transport due to ion temperature gradient (ITG) and trapped electron modes (TEM) [3]. However, the GLF23 model is limited in several respects. It uses a trial wavefunction solution for the eigenmode that is only accurate over a limited range of parameters such as magnetic shear. It only has shifted-circle magnetic geometry and assumes high aspect ratio for the trapped electrons. Two different models are used for TEM and electron temperature gradient (ETG) modes. GLF23 is usually run without electromagnetic terms due to the restricted geometry. Despite these limitations, the GLF23 model is a fairly good representation of turbulence simulations of the core of tokamaks for shifted circle geometry when ITG and TEM modes are dominant. However, GLF23 was never designed to be valid in the strong shear region near the edge. The impact of shaped magnetic surfaces on H-mode edge stability and the pedestal structure is becoming increasingly appreciated. The low aspect ratio spherical tori introduce a host of new transport physics and ETG modes are possibly more important [4].

The new TGLF transport model removes the GLF23 limitations and is a much more accurate fit to gyrokinetics. The kernal of the TGLF model is the new gyro-fluid equations used to compute the linear eigenmodes [1]. A model for the averaging of the Landau resonance by the trapped particles seamlessly unifies the trapped and passing particles into a single set of moment equations. An example of this is shown in Fig. 1. Here the linear growthrate spectrum for the most unstable mode at each wavenumber is shown for both a gyrokinetic code [5] (dashed) and the TGLF model (solid). The TGLF eigenmode solution can follow both the ion and electron branches separately. The point at which they exchange dominance agrees with the gyrokinetic code. Trapped electrons are important in extending the electron branch to low wavenumber. The new TGLF model gives linear eigenmodes which are a much better representations of the gyrokinetic linear modes than the GLF23 equations. This is illustrated in Fig. 2. The fractional standard deviation between the growth rate computed with a gyrokinetic code [5] and the two gyrofluid models is plotted for five cases. Each case is a scan of magnetic shear ($1 < s < 7$) and safety factor ($3 < q < 7$) with 80 points total. The normalized pressure gradient (α) is different for each case. All of the cases have the other plasma parameters fixed ($a/L_{ne}=a/L_{ni}=3$, $a/L_{Te}=a/L_{Ti}=10$, $T_i/T_e=1$, $k_y=0.3$, $r/a=0.75$, $R/a=3$). These parameters are similar to those found near the edge of tokamaks. However, shifted circle geometry is used with zero beta and no collisions for the cases in Fig. 2 which is not similar to real tokamaks. From Fig. 2 it is clear that the GLF23 model does not track the α dependence. The new TGLF model gives a uniformly good growth rate as α is varied. The average fractional standard deviation for a database with 1799 points total

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over a wide range of plasma parameters is 11.4% [1]. The TGLF equations are solved using an adaptive Hermite-basis function technique rather than the trial wavefunction approach of GLF23. Using this method, the TGLF equations can be solved for linear eigenmodes without iteration or branch finding and without the time step limitations of initial value solutions. This allows the finding of eigenmodes at high collision frequency or high beta. Shaped magnetic geometry has been included using the Mercier-Luc-Bishop method [6]. The Miller geometry model [7] for shaped flux surfaces is implemented. Collisions and finite beta electromagnetic terms are also included in TGLF.

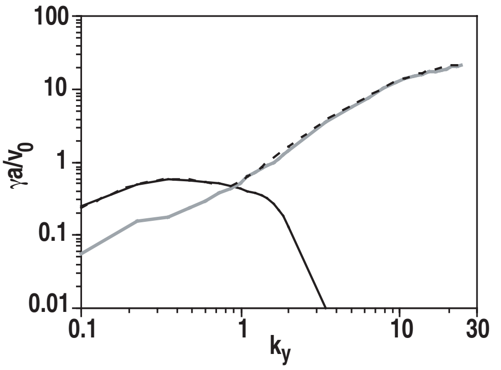

Fig. 1. Linear growthrate for the most unstable mode from a gyrokinetic calculation (dashed) and the TGLF eigenmode growthrate (solid) for the most unstable ion branch (black) and electron branch (grey) over a wide range of poloidal wavenumber.

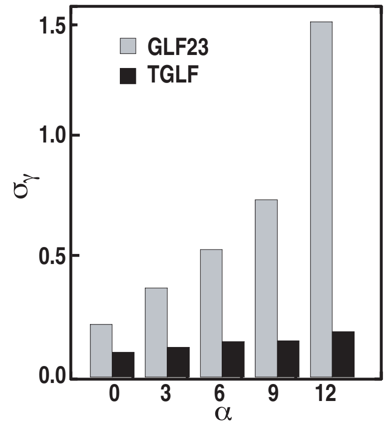

Fig. 2. Standard deviation between the growth rate computed with an exact gyrokinetic code and the two gyrofluid models GLF23 (grey) and TGLF (black).

The TGLF transport model is built on a theory-based philosophy. The model uses the linear eigenmodes of the TGLF equations. The transport due to these modes is approximated using quasi-linear theory and a model for the saturated fluctuation amplitude of the turbulence. The saturation model was designed to fit the energy fluxes in nonlinear numerical simulations of the turbulence. No fitting to experiment was done, so the model is a test of the physics it includes. A large database (>300) of nonlinear turbulence simulations using the full physics gyro-kinetic code GYRO [8] has been collected [9]. This database was used to fit a mixing length model for the saturation of the turbulence amplitude used in the TGLF transport model. This database is a very large improvement over the limited gyrofluid turbulence simulations used to construct GLF23. The new database of GYRO runs includes fully kinetic electrons and ExB velocity shear. Scans over magnetic shear and most of the other plasma parameters are included in the database. There is good agreement between the various gyrokinetic turbulence codes for conditions where ITG and TEM modes are dominant. The saturation of the ETG modes at high poloidal wavenumber is based on new GYRO simulations with kinetic ions. The first comparisons of the TGLF transport model with experimental data will be presented.

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