UKAEA-CCFE-CP(19)47

B. Patel, C. Challis, D. Dickinson, L. Garzotti, F. Koechl, C. Roach, G. Staebler, H. Wilson

Benchmarking the TGLF turbulent transport code for a Q=10 burning spherical tokamak plasma using GS2

Benchmarking the TGLF turbulent transport code for a Q=10 burning spherical tokamak plasma using GS2

B. Patel, C. Challis, D. Dickinson, L. Garzotti, F. Koechl, C. Roach,
G. Staebler, H. Wilson

This paper has been submitted to
46th European Physical Society Conference on Plasma Physics (EPS), Milan, 8-12 July 2019

Optimising TGLF for a Q=10 Burning Spherical Tokamak

Bhavin Patel[1,2], D. Dickinson[1], F. Koechl[2], C. Roach[2], G. Staebler[3], and H. Wilson[1,2]

[1] *York Plasma Institute, Department of Physics, University of York, YO10 5DD, UK*
[2] *Culham Centre for Fusion Energy, Abingdon, Oxfordshire, OX13 3DB, UK*
[3] *General Atomics (GA), P.O. Box 85608, San Diego, CA, 92121, USA*

Abstract

TGLF transport model predictions have been assessed in the vicinity of a theoretical high β burning plasma spherical tokamak at Q=10. Linear micro-stability calculations from TGLF have been compared on a surface at mid-radius with the gyrokinetic code GS2. Differences between TGLF and GS2 spectra can be characterised by the RMS difference in growth rates, σ_γ. We find considerable improvement in the quality of TGLF growth rate spectrum can be achieved by increasing the number of parallel basis functions and by tuning the TGLF parameter used in the model for trapped particles, θ_{trap}.

1 Introduction

The fusion performance of a Burning Spherical Tokamak (BurST) will be critically dependant on the quality of confinement, and the plasma will be in a regime where no other machine has operated. While it is possible to extrapolate the confinement using existing global scaling laws (e.g. H^{98} [1] and $H^{Petty08}$ [2]), obtaining higher fidelity predictions requires using physics based models like TGLF [3, 4]. However, TGLF remains largely untested in the extreme parameters space of BurST. This work sets out to address this.

A candidate Q=10 design has been proposed based on a confinement assumption, using the fixed boundary equilibrium solver SCENE and the NUBEAM code [5]. The neutral beam configuration was chosen to generate a current profile suitable for non-inductive operation. The temperature and density profiles, including the pedestal height were prescribed, consistent with the Q=10 requirement. This equilibrium is used to explore TGLF predictions for the core plasma. The pedestal region requires its own separate study and is not examined here.

TGLF solves the linear Gyro-Landau fluid equations and uses the eigenmodes to calculate the quasi-linear fluxes of energy and particles. A model for the saturated fluctuation intensity has been created by comparisons to non-linear simulations with GYRO, allowing for estimation of absolute fluxes.

JINTRAC [6], a integrated modelling suite has been used to model the heat transport in BurST and predict the temperature profiles. The neoclassical transport has been calculated using NCLASS [7], and the anomalous transport with TGLF.

Starting with the target SCENE equilibrium, the electron and ion temperature profiles were evolved until a steady state solution was reached with TGLF's default settings. The fusion power falls from $P_{fus} = 1.1GW \rightarrow 350MW$. Increasing the number of TGLF parallel basis functions used to fit the eigenmode to 8 reduces the transport and provides temperatures profiles consistent with $P_{fus} = 1.3GW$. This highlights that TGLF predictions for BurST are highly sensitive to TGLF's tuning parameters, which motivates our goal to verify TGLF via direct comparisons with the local gyrokinetic code GS2 [8], with a view to improve TGLF predictions in the burning ST regime.

2 TGLF default settings

The default parameters for TGLF include to ignore the pressure component to the curvature drift and use 4 basis functions to fit the eigenmode. Furthermore, TGLF has a tunable parameter called θ_{trap} setting a boundary to divide the treatment of trapped particles as either resonant or Landau averaging, which directly impacts the trapped electron drive. To consistently calculate this boundary the parallel wavenumber is needed, yet it is not known before the calculation. The choice of θ_{trap} is effectively a guess at $k_{||}$. $\theta_{trap} = 0.7$, by default, as this value minimised the fractional error between TGLF and GKS [9] growth rates for DIII-D like equilibria [10]. In an ST the trapped particle fraction is much larger than for a conventional device like DIII-D, so θ_{trap} was re-optimised for BurST. This work examines a mid flux surface $r/a = 0.5$.

3 Simplified geometry

Using the SCENE equilibrium the local Miller parameters, like elongation and triangularity, were determined. Before exploring this challenging equilibrium, a simplified

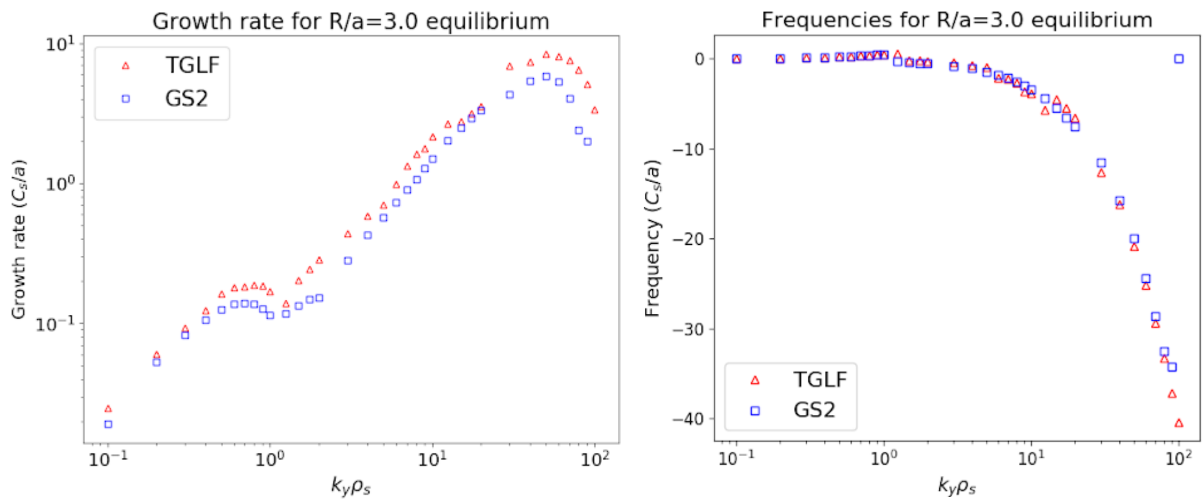

Figure 1: Linear growth rates (left) and frequencies (right) of the mode calculated by GS2 and TGLF for a $R/a = 3.0$, $\beta = 0$ equilibrium. Qualitative agreement can be seen between the two, with the change in frequency, indicating switching to a new branch occurring at the similar $k_y\rho_s$.

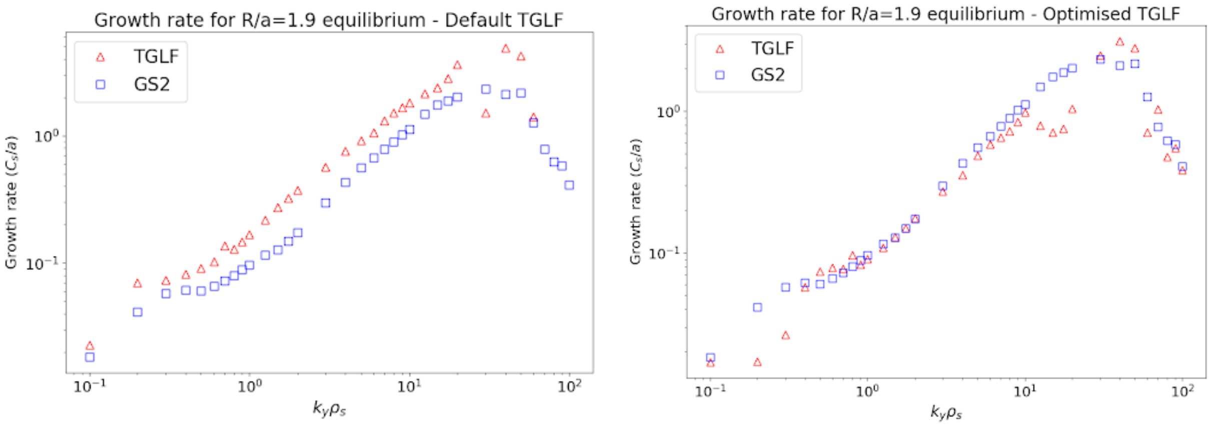

Figure 2: Linear growth rates calculated by GS2 and TGLF for a $R/a = 1.9$, $\beta = 0$ equilibrium. With default TGLF settings (left) and optimised settings (right). Increasing the number of basis functions and setting $\theta_{trap} = 0.4$ results in the lowest σ_γ.

version was examined where $\beta = 0$, $\beta' = 0$ and the aspect ratio was artificially increased from $R/a = 1.9 \to 3.0$. The linear growth rate spectra from the two codes for these electrostatic modes are shown in Figure 1.

With default TGLF input parameters, the linear growth rates from TGLF exceed the growth rates predicted by GS2, with the RMS fractional difference $\sigma_\gamma = 58\%$. Increasing the number of TGLF basis functions to 8 reduces the difference to $\sigma_\gamma = 45\%$.

We have also considered an equilibrium with a consistent aspect ratio of $R/a = 1.9$, at $\beta = 0$. The results are shown in Table 1 where σ_γ is examined in three regions, $k_y\rho_s < 1$ (low), $1 < k_y\rho_s < 10$ (mid) and $k_y\rho_s > 10$ (high). Again, increasing the number of basis functions from 4 to 8 reduced σ_γ, this time from 77% to 55%. If θ_{trap} is set to 0.4, then this is further reduced down to 29%. Figure 2 shows the linear growth rates. It can also be seen that around $k_y = 10$, for the modified settings, TGLF and GS2 diverge quite a bit as it appears TGLF picks up a different mode, raising σ_γ to 38%.

By increasing the number of basis functions further from 8 to 16, the agreement in the low and mid regions can be improved further. Curiously, however, TGLF the high

	4 basis $\theta_{trap} = 0.7$	8 basis $\theta_{trap} = 0.7$	8 basis $\theta_{trap} = 0.6$	8 basis $\theta_{trap} = 0.5$	8 basis $\theta_{trap} = 0.4$	8 basis $\theta_{trap} = 0.3$
$\sigma_\gamma^{low}(\%)$	56	60	44	32	30	40
$\sigma_\gamma^{mid}(\%)$	86	58	48	29	12	58
$\sigma_\gamma^{high}(\%)$	80	50	36	43	38	48
$\sigma_\gamma^{total}(\%)$	77	55	43	36	29	50

Table 1: Differences in the growth rates for 3 different regions in k_y (low, mid and high - see text) for $R/a = 1.9$. Increasing the number of basis function reduced σ_γ. Reducing θ_{trap} reduced the differences in the low to mid k_y regions. Colours correspond to $\sigma_\gamma > 50\%$, $30\% < \sigma_\gamma < 50\%$ & $\sigma_\gamma < 30\%$

k_y modes are stable when using 16 basis functions, but again are unstable with 32 basis functions. This discrepancy should be examined. The difference in σ_γ between 8 and 32 was not significant and the increased number of basis functions would be computationally expensive in a transport solver. 8 basis functions appears to be a good balance of accuracy and speed. Another option is to have the number of basis functions depend on k_y.

4 Conclusions

The TGLF linear electrostatic micro-instability predictions have been compared with local gyrokinetic calculations using GS2 for highly shaped equilibria at $R/a = 3.0$ and $R/a = 1.9$, where the other local parameters are taken from a SCENE equilibrium for BurST. We have explored the sensitivity of the TGLF results to the number of basis functions and the value of θ_{trap}. For the local equilibrium with $R/a = 3.0$, the default TGLF settings resulted in a $\sigma_\gamma = 58\%$. Increasing the number of basis functions to 8 reduced this to $\sigma_\gamma = 45\%$. Similarly at $R/a = 1.9$ increasing the number of basis functions to 8 and reducing the value of $\theta_{trap} = 0.4$ dropped σ_γ from 77% to 29%. This indicates that the default TGLF parameters can be adjusted to improve the model's description of electrostatic micro-instabilities in STs. Note that the parameters found here may not be suitable for all flux surfaces, and other surfaces must be studied to assess the optimal values. A more self-consistent approach, with a modest additional computational cost, may be to update θ_{trap} using the $k_{||}$ after a first iteration, and use this to recalculate the impact on trapped particles. Future work will compare TGLF with local gyrokinetics for high β equilibria, where fluctuations in the magnetic field are more important; this will be the regime necessary to optimise the efficiency of fusion power production.

This work was supported by the Engineering and Physical Sciences Research Council [EP/L01663X/1]. This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

References

[1] ITER Physics Basis 1999 Nucl. Fusion 39 2137

[2] C.C. Petty, Physics of Plasmas 15 080501, 2008.

[3] G.M. Staebler, J.E. Kinsey, and R.E. Waltz., Phys. Plasmas, 14:055909, 2007.

[4] G.M. Staebler and J.E. Kinsey., Phys. Plasmas, 17:122309, 2010.

[5] A. Pankin, et al., Computer Physics Communications 159.3 157-184, 2014.

[6] M. Romanelli, et al., Plasma and Fusion research 9, 3403023, 2014.

[7] S. Breton et al. Phys. Plasmas 25, 012303, 2018.

[8] M. Barnes et al 2019, (June 10) GS2 v8.0.2 (Version 8.0.2). http://doi.org/10.5281/zenodo.2645150

[9] M. Kotschenreuther, Bull. Am. Phys. Soc. 37 1432, 1992.

[10] G.M. Staebler, J.E. Kinsey and R.E. Waltz., Phys. Plasmas, 12:102508, 2005.