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Fundamental and exotic features of global resistive MHD instabilities in advanced tokamak regimes

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Abstract. The rush to build electricity producing tokamak reactors implies that empirically led physics basis must be increasingly replaced by theory and modelling. Particularly urgent is the design of robust scenarios that are stable to MHD instabilities, despite key differences in reactor plasma equilibria relative to present day machines. One approach is to deploy high fidelity codes, but very often this is at the cost of losing trace of individual physics effects, all of which should be understood for plasma scenario design. In addition large codes often neglect fundamental exotic details in favour of isolating the fastest growing instabilities. By considering toroidal coupling between modes, resistive dissipation and compressibility, we present a light approach to modelling long and moderate wavelength MHD instabilities. This allows a precise investigation into the implications of each of these effects on performance limiting instabilities, especially on resistive infernal modes. Reference [1] presented a unified and global analytic description of internal toroidal instabilities, and hinted at the development of a new reduced resistive eigenvalue solver. Here we present applications of this work to different kinds of advanced/hybrid scenarios. These scenarios typically have extended regions of low magnetic shear, and are therefore particularly sensitive to the details of toroidicity and other ordinarily weak driving effects.

We extend [2] by initially investigating cases with low magnetic shear in regions of unfavourable average curvature. Well known stability criterion of interchange modes are modified strongly by the weak ballooning effects of global infernal drive. Stability properties of internal transport barriers in reversed shear configurations are also studied, revealing effects of infernal drive and damping by average good curvature in the face of resistive dissipation on the global eigenfunctions in regions of low and high shear. Taking a step further, we retrieve shorter radial wavelength modes (analytically described by [2]) ordinarily not obtainable with high fidelity codes. For the first time we show that a spectrum of unstable modes exists in the region of vanishing average curvature, which occurs at $q = 1$ in a toroidal plasma with circular cross sections. A novel analytical description of this resistive internal kink spectrum, with arbitrary $m$ for non resonant $q = 1$ unstable spectra is also provided. Such cascades of modes could be connected with sawtooth crash events or the avoidance of the crash via long living modes with $q \approx 1$ sustained. By extending some of the concept in [3] to include unstable short wavelength modes, we hope to gain fundamental understanding into key tokamak macroscopic reconnection events.

References
Kinetic ballooning modes as a constraint on plasma triangularity in commercial spherical tokamaks

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Abstract. To be economically competitive, spherical tokamak (ST) power plants require high \( \beta \) (plasma pressure/magnetic pressure) and sufficiently low turbulent transport to enable steady-state operation. A novel approach to tokamak optimisation is negative triangularity, with experimental results indicating this reduces transport in L-mode, and avoids the deleterious impact of Edge-Localised Modes (ELMs) experienced in standard H-mode operation. However, negative triangularity is known to close access to the “second stability” region for ballooning modes. Since second stability access is usually important in ST reactor design, this raises the question of whether negative triangularity is feasible. We address this by presenting a linear gyrokinetic study of three hypothetical (but reasonable) high \( \beta \) ST equilibria with similar size and fusion power in the range 500-800MW. We find that the negative triangularity equilibrium becomes strongly unstable to long-wavelength kinetic ballooning modes (KBMs) across the plasma, likely driving unacceptably high transport. By contrast, positive triangularity with reactor-relevant \( \beta \) can completely avoid the ideal MHD ballooning unstable region, provided the on-axis safety factor is sufficiently high. The dominant instability still appears to be KBM, but the growth rate is low; this could feasibly be stabilised by flow shear or may impose a soft \( \beta \) limit.
Analytic model of $m = 1$ magnetic flux pumping

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Abstract. Nonlinear MHD simulations of the $m = n = 1$ mode in the core of tokamak plasmas have demonstrated [1, 2] the possibility of a saturated mode with steady $m = 1$ convective motion balancing the resistive relaxation of the $q$-profile in a process dubbed “magnetic flux pumping”, giving rise to a central region with very low magnetic shear ($q \approx 1$) despite the presence of a loop voltage and a peaked conductivity profile. It was noted [1, 2, 3] that such low-shear zone is unstable to the pressure-driven $m = 1$ quasi-interchange mode, and the numerically obtained flow pattern was found to be in agreement with the linear eigenfunction of the quasi-interchange [4]. The present paper follows up on the idea that the steady state flux pumping may be viewed as a resistive saturated state of the quasi-interchange mode.

An analytic reduced MHD description is given of the saturated quasi-interchange mode, the saturation being the result of nonlinear deformation of the magnetic surfaces in the presence of a pressure gradient. In the presence of resistivity this state has a slow residual $m = 1$ flow. The flux pumping consists of two nonlinear effects by which the $m = 1$ perturbation affects the ($m = 0$) radial profiles: (1) the flow provides the radial transport of flux within the core $q \approx 1$ region by the dynamo effect described in [1, 2, 3], and (2) the $m = 1$ deformed flux surfaces correspond to $m = 1$ perturbations of the current density, the resistive decay of which provides the necessary second step of removing flux from the core region. (Note that the dynamo term of effect (1) alone integrates to zero over the plasma core).

Stability of this $m = 1$ state is analyzed, showing that it can be stable in cases where the axisymmetric equilibrium with central $q$ well below unity is stable to the quasi-interchange mode: a true bifurcated equilibrium. The $m = 1$ flow also causes convective heat transport. Inclusion of this transport in the model results in a smaller $m = 1$ amplitude due to reduced peaking of the conductivity profile and the pressure profile.

References
Gyrokinetic Stability Analysis of JET Pedestal Top in Small-ELM Regime

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Abstract. The standard operational regime of tokamaks in the last decades has been the high-confinement mode (H-mode), since its discovery in 1982. The steep gradients which form in the edge region are responsible for the occurrence of edge localized modes (ELMs). However, the energy and particle fluxes on plasma facing components due to the so-called Type-I ELMs will not be sustainable at reactor scale. For this reason, in the last years, a strong effort has been dedicated to the development of alternative regimes to the standard Type-I ELM H-mode, i.e. ELM-free and small-ELM regimes \cite{Viezzer2018}. In these regimes, the peeling-ballooning boundary limit for the onset of Type-I ELM is prevented thanks to a transport mechanism which modifies the pedestal structure.

In this work, we will focus on the new H-mode regimes with small-ELMs, high thermal confinement, and low core impurity accumulation recently found at JET \cite{Garcia2022}. The goal is to characterize the microturbulence at play at the top of the pedestal to understand the transport mechanism. To this end, an extensive local linear gyrokinetic analysis with the GKW code \cite{Peeters2009} has been carried out. In particular, a comparison between a reference Type-I ELM (\#97395) and two small-ELM regimes (\#96994 and \#94442) has been performed.

We found that the ion-scale ($0.1 \leq k_{\theta_1} \rho_i \leq 2$) is characterized by micro-instabilities with different nature depending on the regimes. Indeed, kinetic-ballooning modes (KBM) are destabilized in the Type-I ELM regime at $k_{\theta_1} \rho_i \sim 0.1$, while they are stable in small-ELM regimes, where ITG-TE modes are dominant. The Type-I ELM regime low-$k_{\theta_1} \rho_i$ part of the spectra reveals higher growth rates and negative (i.e. electron-diamagnetic-direction) frequencies starting at lower $k_{\theta_1} \rho_i$ than small-ELM regimes. Meanwhile, at electron-scale ($10 \leq k_{\theta_1} \rho_i \leq 700$) electron temperature gradient (ETG) modes are the dominant micro-instabilities in all discharges. In all cases, we found that the growth rate at electron-scale peaks at very small scale, $k_{\theta_1} \rho_i \sim 200$, which can happen in the edge \cite{Told2008}. Then, since small-ELM regimes are characterized by a higher impurities content at the pedestal, particular attention has been given to the role played by them. We found that impurities represent a critical player in the linear dynamics, strongly affecting the nature of micro-instabilities at ion-scale.

In the end, a quasi-linear investigation is carried out, which reveals the differences in the role played by turbulent transport in the two regimes, and will guide the following non-linear investigation. The aim will be to clarify the different type of turbulence at the top of the pedestal in Type-I ELMs versus small-ELMs and the role played by impurities and flows on turbulent fluxes, which will be validated against experimental measurements.

References:
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Triangularity effects on global flux-driven gyrokinetic simulations

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Abstract.
On the road to fusion energy production, many alternative scenarios have been investigated in order to address certain well-known problems of tokamak devices; among which, anomalous transport, ELMs and disruptions. The studies on plasma shaping fall into this effort. Recently, the interest in negative triangularity has been renewed thanks to encouraging experimental findings obtained in the TCV and DIII-D devices [1, 2]. In particular, it has been observed that negative triangularity (NT) features improved energy confinement with respect to positive triangularity (PT), when both operate in L-mode. However, even though the trend is quite clear, a complete and satisfying theoretical explanation for this result is still lacking. With the aim of understanding and describing these improvements starting from first principles, we present the first comparison between PT and NT with global flux-driven gyrokinetic simulations performed with the ORB5 code [3].

The numerical setup includes: electrostatic turbulence, kinetic trapped electrons, non-linear collisional operator, ECRH source, limiter and wall as boundary conditions. The simulations have been performed on ideal MHD equilibria and kinetic profiles inspired by TCV experiments, in a mixed ITG-TEM regime.

Non-linear simulations point out the improved NT energy confinement, similar to the experiments. This similarity is lost if collisions or kinetic trapped electrons are not considered.

Even though the geometrical difference of triangularity is mostly at the edge, its beneficial effect spreads inside, stressing the importance of global simulations and ultimately of non-local effects that play a crucial role. The electron heat and particle fluxes are characterized by avalanches with fronts propagating inwards from the last closed flux surface. The direction of propagation of the fronts is related to the sign of the time-averaged shearing rate of the $E \times B$ zonal flow. The shearing rate is in turn influenced by the triangularity, leading to differences between the two equilibria. In addition, the shearing rate is also strongly influenced by the boundary conditions. Next to the limiter a large shear develops for both triangularities, even though differences appear between the two cases.

Gyrokinetic turbulence studies of the transition from open to closed field lines in tokamaks

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The edge of tokamak plasmas is characterized by large density and temperature gradients. The transport in this region is critical since it governs the energy content of the plasma, hence determining its overall performance in terms of fusion gain. In some cases, turbulent transport is locally reduced in the edge, leading to enhanced plasma confinement. The transition from a low confinement (L-mode) to a high confinement (H-mode) is routinely observed in most tokamak plasmas. The L to H mode transition is correlated with the deepening of the radial electric field well, possibly governing the shearing of turbulent structures and the subsequent reduction of turbulent transport. The origin of this sheared radial electric field is not fully understood yet, nor the precise mechanisms by which it impacts turbulent transport. However, the transition from closed to open field lines is clearly identified as a key ingredient for the formation of the electric field well at the edge.

The impact of the transition from closed to open field lines \cite{1} on the plasma has been studied by means of global flux-driven simulations performed with the GYSELA code, using adiabatic electrons. These simulations pointed out the critical role of the transition from closed to open field lines in the organization of turbulence in the edge of tokamak plasmas \cite{2}.

The model in GYSELA has recently been extended to treat trapped electrons kinetically whereas passing electrons are considered as adiabatic. The immersed boundary conditions have been improved consistently, assuming an adiabatic response for electrons with trajectories intercepting the limiter and a kinetic response for the other electrons in the scrape-off-layer. A similar work has been performed in the ORB5 code and a qualitative agreement with GYSELA results is found. As in adiabatic electron simulations, a sheared radial electric field is observed to develop at the transition between closed and open field lines. It results from the boundary conditions as well as turbulence spreading. Its characteristics also depend on plasma shaping. A quantitative comparison of edge organization between simulations with adiabatic electrons and simulations considering a partial kinetic electron response will be presented.

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Magnetic Structure of Turbulence-Driven Magnetic Islands

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Abstract.

Neoclassical tearing modes (NTM) are metastable magnetic islands in tokamaks; however, they appear frequently in experiments without any noticeable triggering event. In order to understand this, it has been numerically shown that turbulence can create a seed island by mode coupling \cite{1, 2, 3}, even remotely \cite{4}; such a seed island has been shown in 2D models to further grow from the NTM mechanism \cite{5}. This amplification happens because of the island-induced pressure profile flattening. In turn, this flattening comes from the transport properties of the island, which are a consequence of the magnetic field perturbation. Therefore, characterizing magnetic transport both inside and outside a turbulence-driven magnetic island is crucial to understanding NTM triggering.

In this work, 3D reduced-MHD simulations of flux-driven ballooning turbulence are used to study the seed island creation in regimes where the classical tearing mode is linearly stable. A localized pressure source is used to control the radial position and strength of the turbulence. The generated island shape is significantly different from what is observed in 2D monohelicity simulations.

The magnetic field structure is characterized inside and around the turbulence driven island. It is shown that stochasticity appears in the turbulent region at low turbulence intensity, and spreads in the stable region for higher intensities. However, significant stickiness of the field lines close to remaining KAM torii is present, which is expected to limit the transport close to such islands.

In this situation, even the definition of island size (or island boundary) becomes ambiguous. This is of particular importance since it is expected that flattening of the pressure profile appears only above a critical island size, depending on the ratio of parallel to perpendicular transport \cite{6}. Several definitions of island size are compared, and a method for sorting magnetic field lines and calculating island width from Poincaré plots is presented.

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A Gyrokinetic moment-based method to model the plasma boundary of fusion devices at arbitrary collisionality

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Abstract. We present a new first-principles model that allows for the proper simulation of the tokamak plasma boundary [1,2]. Developed onto a set of fluid-like equations that retain the gyrokinetic Coulomb collision operator, the gyro-moment (GM) model offers a modelling framework able to describe the fluctuations occurring on a large range of spatial scales present in the plasma boundary where the plasma collisionality can vary by orders of magnitude. In fact, the GM model contains the core gyrokinetic model and the fluid and gyrofluid models used for scrape-off layer simulations as special limits. We illustrate the analytical and numerical capabilities of the GM model by considering different parameter regimes relevant for boundary. We demonstrate that the GM approach can correctly retrieve the properties of microinstabilities that develop at low plasma collisionality, strongly sensitive to kinetic features, in perfect agreement with the GK continuum GENE code. At the same time, we show that the use of advanced GK collision operators, such as the GK Coulomb collision operator, allows us to properly retrieve the fluid limit of the plasma dynamics at high collisionality. We demonstrate that the GM approach is numerically efficient for the simulations in plasma regimes that range from the low-collisionality banana regime in the H-mode pedestal to the high-collisionality regime of the scrape-off layer in L-mode discharges. Through our first nonlinear simulations, we investigate differences with commonly used collision operator models and show that, due to deviations that lie in the linear growth rates and zonal flow damping [3,4], turbulent transport level in the boundary can be largely underestimated if simplified collision operators are used.

References
Kinetic Chodura condition at the magnetised plasma sheath with turbulence

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Abstract. A charged Debye sheath typically forms in plasmas next to a solid target in order to repel the mobile electrons and achieve a steady state. The Bohm condition states that it is necessary for normal plasma flow into the Debye sheath to be at the sound speed in order for the strong sheath electric field to decay monotonically far from the target [1]. The Chodura condition states that plasma flow parallel to the magnetic field entering the magnetised plasma sheath, which consists of a Debye sheath and a much wider magnetic presheath, must be sonic. While the kinetic generalisation to the Bohm condition has been extensively derived, all previous derivations of the kinetic Chodura condition neglect or simplify the contribution of the ion polarisation drift [2, 3, 4]. This is a key mechanism that drives the presence of a strong electrostatic potential variation on the length scale of the ion gyro-radius, which is the trademark of the magnetic presheath. Any conclusion on the existence of a monotonically decaying presheath electric field must account for a possible reversal of the sign of the ion polarisation density due to tangential gradients. We show that strong spatial structures tangential to the target can cause such a reversal. This could have implications on the stability of the magnetic presheath and on the sheath boundary conditions that will have to be imposed on gyro-kinetic codes. We also numerically obtain steady state kinetic solutions of magnetic presheath profiles by imposing, far from the target, ad hoc small-amplitude spatial fluctuations (which could be caused by turbulence) tangential to the target, thus characterising the spatial structures at the target. Our analysis excludes collisions in the magnetic presheath.

References
Role of avalanche transport in competing drift wave and interchange turbulence

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Abstract. Assessing the role and weight of avalanche transport in plasma turbulence is an open issue. It is a key point of turbulence self-organization connected to the competition between the source of transport and the effective characteristic time scale of turbulent transport, in particular its dependence on the amplitude of the fluctuating field. Strong drive by the source near marginal coarse-grained gradients will tend to trigger relaxation events with bursts of turbulent transport governed by self-organized avalanches. These also appear to exhibit an interplay with zonal flow structures as in the stair case regime [1].

Many studies of avalanche transport have been achieved for Scrape-Off Layer conditions with poloidally homogeneous conditions and interchange linear instability [2, 3]. In this work, we extend this physics to poloidally localized interchange instability conditions and investigate the competition with the occurrence of drift wave linear instability in the edge and SOL regions [4]. Simulations are performed with a generalized version of the code TOKAM2D [5]. Avalanche transport in statistical steady state conditions is monitored on the one hand by the localization and radial propagation of the transported flux, and on the other hand, by the properties of its probability distribution function compared to that of the electric potential and transported field. Decaying interchange turbulence conditions are poloidally localized to the high field side region. Despite the low fluctuation level in this region, significant transport is observed because the remnant potential spectrum is narrowed to the least stable mode. This exemplifies a key aspect of the self-organized relaxation events, namely the competing efficiency in terms of transport and amplitude of the source driving the system away from marginality. The width of the SOL and its dependence on the various possible instabilities is investigated and compared to available reduced models, such as the k-epsilon model. The scaling law of the SOL width is also investigated and found to be proportional to rho* - typically the mesh size at the Larmor radius divided by the size of the simulation domain - with a dependence on the safety factor governed by the time scale of parallel losses. The value of the proportionality factor and the dependence on the aspect ratio is also addressed when modifying the balance between the instabilities.

References
Stability of a weakly collisional plasma with runaway electrons

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Abstract. We address here the problem of the tearing stability of a post-disruption weakly collisional plasma where the current is completely carried by runaway electrons. The final goal is to extend the work in \cite{Helander07}, where a resistive plasma was considered, to regimes where the magnetic reconnection is governed also by ions sound Larmor radius and electron inertia effects. Specifically, it has been demonstrated in \cite{Helander07} that the presence of runaway electrons in plasma has a significant effect on the saturated magnetic island width. In particular, runaway electrons generated during disruption can cause an increase of 50\% in the saturated magnetic island width with respect to the case with no runaway electrons. These results were obtained adopting a periodic equilibrium magnetic field that limited the analysis to small size saturated magnetic islands. Here we present our results to overcome this limitation adopting a non-periodic Harris’ type equilibrium magnetic field. Preliminary results on the effects of the ion sound Larmor radius effects will also be presented. Future work foresees also to consider oblique modes as in ref. \cite{Liu20}.

References
Unified linear and nonlinear treatment of tearing modes driven by infernal modes and bootstrap current

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Abstract. Large sustained tearing modes remain a serious concern for future tokamak operations. In addition to the obvious direct disruption risk, particularly in a weakly rotating reactor plasma where internal modes easily lock to the wall, it has been observed that neoclassical tearing modes (NTMs) can cause intolerable accumulation of heavy impurities in a modern tokamak with a tungsten divertor [1]. NTMs are frequently seeded by sawteeth, and by non-resonant kink-infernal modes during hybrid scenario operations [2, 3]. This contribution models the process of tearing mode seeding by infernal modes. It derives and solves the tearing mode equations smoothly through the linear and non-linear regimes, taking into account the drive from bootstrap current and infernal modes. The tearing modes are seeded on the rational surfaces of the upper sidebands of the infernal modes [4], these being toroidal coupled to the $q \approx 1$ main harmonic. In order to model the amplitude of the drive from infernal modes, the saturated non-linear amplitude of the infernal modes are calculated. Considered in this work are $m = n = 1$ and $m = n \neq 1$ modes, extending the linear kink calculations of [5] to include non-linear saturation.

References
Towards a reduced transport model for microtearing turbulence in H-mode plasmas

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Abstract. In magnetic confinement fusion research, the causes of electron heat transport are still not fully understood. Analysis of conventional tokamak plasmas \cite{1, 2, 3} suggests that microtearing (MT) mode, may be responsible for electron heat transport in the pedestal, and thereby play some role in determining the pedestal characteristics. MTs belong to a class of instabilities where a modification of the magnetic field line topology is induced at the ion Larmor radius scale. This leads to the formation of gyroradius-scale magnetic islands, which can enhance the electron heat transport\cite{1, 4}. The stability of MT modes has been extensively studied theoretically, showing that a slab current sheet is stable in the absence of collisions\cite{5, 6}.

In order to predict the electron heat transport due to MT in the tokamak pedestal, and to aid with the development of a quasilinear MT transport model, nonlinear simulations were run with the Gene code and analyzed with respect to magnetic fluctuations and the question which kind of physics sets the saturation amplitudes in the quasi-stationary turbulent state. This is a key prerequisite for developing a reduced MT model applicable for flux-driven integrated modeling.

Here analysis of a database of nonlinear gyrokinetic simulations shows that a quasilinear transport model for microtearing transport reproduces gyrokinetic trends for a variety of parameter regimes. The impact of various physical parameters, particularly the electric potential, on nonlinear saturation is examined using this simplified model. The electric potential plays a key role in microtearing destabilization by boosting the growth rate of this instability in the presence of collisions, whereas in electrostatic plasma micro-turbulence, zonal flows can have a strong stabilizing impact in turbulent saturation. Here, instability and saturation physics are examined for different pedestal cases and radial positions, with a special focus on the role of electric field fluctuations and the role of zonal flows and fields. In the saturated state, it is found that removing the zonal flow and zonal fields causes a flux increase, whereas linearly stabilization had been observed. This model will be coupled to a neural network for sweeping parameter scans, working towards real-time transport modeling in particular of the tokamak pedestal.

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A kinetic model of ions and neutrals with wall boundary conditions in edge plasmas

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Abstract. Fluid models dominate the field of edge transport modelling, for the good reason that the edge plasma is colder and more collisional than the hot core plasma, see, e.g. [1-2]. However, there is increasing interest in developing edge kinetic models, see, e.g. [3-5]. This is for two main reasons: first, edge models must take a boundary condition from the hot core plasma, where turbulent transport must be modelled kinetically; second, kinetic effects in the edge may be important in themselves. One source of kinetic behaviour can plausibly arise from the presence of the wall or sheath boundary conditions that must be imposed on the plasma at the divertor plate [6]. Another such effect could arise from the interactions between charged and neutral particles -- unlike charged particles, neutral particles easily cross magnetic flux surfaces and undergo complex collisions with ions and electrons [7-8]. We present a simple full-f model of an edge plasma with helical geometry, including ions, neutral particles, wall boundary conditions, simple charge-exchange and ionisation collision operators, and Boltzmann electrons. The model is implemented in Julia. A testing framework has been developed to allow for automated manufactured solutions tests that cover all features implemented in the model. We present a selection of these tests that illustrate the performance capabilities of the spectral-element discretisation and the strong stability preserving Runge-Kutta time stepping algorithm. We briefly describe an initial physics investigation into the accumulation of neutrals near the wall plates.

References
Upper bounds on gyrokinetic instabilities

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Abstract. For several decades, an enormous effort has been devoted to the gyrokinetic theory of instabilities and turbulence in stellarators and tokamaks. Thousands of papers have been published on this subject, and millions of lines of code have been written for the purpose of numerically solving gyrokinetic equations.

As a result of this effort, a great deal of knowledge about various microinstabilities has accumulated. Ion- and electron-temperature-gradient-driven modes, trapped-electron modes, kinetic ballooning modes and microtearing modes have, for instance, been found to be unstable and cause turbulence in tokamaks and stellarators. However, these instabilities tend to be sensitive to assumptions made about plasma parameters and the magnetic-field geometry. As a result, little is known in general about gyrokinetic microinstabilities, despite the great effort devoted to their study.

Proceeding from thermodynamic considerations, we derive universal upper bounds on the growth rates of local gyrokinetic instabilities in any magnetised plasma, regardless of the geometry of the magnetic field, the number of particle species, beta, and collisions [1,2,3]. A large number of results that have earlier been derived in special cases or observed in numerical simulations are thus brought into a unifying framework. Moreover, these upper bounds hold not only for linear instabilities but also for the nonlinear growth of free energy in a turbulent plasma.

These results are very general and reflect dependencies on plasma parameters that have earlier been derived in special cases. However, they contain little information about the influence of magnetic geometry on instabilities and turbulence, but it is possible to extend the analysis in such a way that more of this information is retained. The result is a family of bounds that do depend on the magnetic geometry, though not as sensitively as do gyrokinetic simulations.

References


Collisional gyrokinetic nonlinear simulations of
turbulent transport based on the projection of the
distribution function on a Hermite-Laguerre basis

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Abstract. The parameters of the plasma in the tokamak boundary challenge the use of current
gyrokinetic and fluid models for the simulation of this region. We present the first nonlinear
gyrokinetic simulations based on a moment approach, which exploits the Hermite-Laguerre
decomposition of the ion and electron distribution functions, showing that this approach is
ideally adapted to simulate the plasma dynamics in boundary conditions. The simulations are
used to evolve turbulence in a local Z-pinch configuration and are accurately benchmarked
against the continuous code GENE in the collisionless regime. Despite the large number
of moments needed for the convergence of the linear growth rate, in the nonlinear regime
the moment approach shows a very good agreement with GENE, even with a reduced set
of moments. By including advanced linear collision operator for the first time we reveal the
fundamental role of the collision operator model in turbulent transport, in particular through
the zonal flows damping. We also show that the convergence of the moment approach is improved
when collisions are included in the system.