# Neural network assisted electrostatic global gyrokinetic toroidal code using cylindrical coordinates

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## Global Gyrokinetic Code using Cylindrical Coordinate

The Gyrokinetic simulation codes are used to understand the microturbulence in the linear and nonlinear regimes of the tokamak and stellarator core. The codes that use flux coordinates to reduce computational complexities introduced by the anisotropy due to the presence of confinement magnetic fields encounter a mathematical singularity of the metric on the magnetic separatrix surface. To overcome this constraint, we develop a neural network-assisted Global Gyrokinetic Code using Cylindrical Coordinates (G2C3) to study the electrostatic microturbulence in realistic tokamak geometries. In particular, G2C3 uses a cylindrical coordinate system for particle dynamics, which allows particle motion in arbitrarily shaped flux surfaces, including the magnetic separatrix of the tokamak. We use an efficient particle locating hybrid scheme, which uses a neural network and iterative local search algorithm, for the charge deposition and field interpolation. G2C3 uses the field lines estimated by numerical integration to train the neural network in universal function approximator mode to speed up the subroutines related to gathering and scattering operations of gyrokinetic simulation. Finally, as verification of the capability of the new code, we present results from self-consistent simulations of linear ion temperature gradient modes in the core region of the DIII-D tokamak.

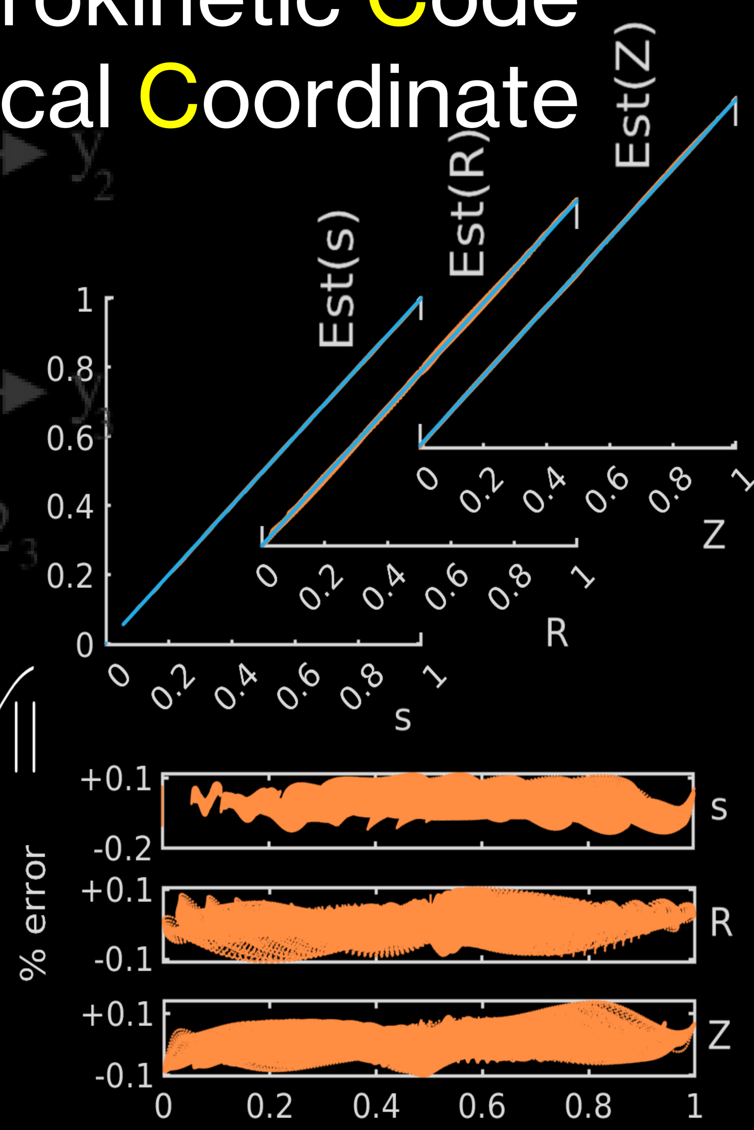
$$\underline{\mathbf{O}} := \underline{\mathbf{W2}}\,\tanh(\underline{\mathbf{W1}}\,\underline{\mathbf{X}} + \underline{\mathbf{B1}}) + \underline{\mathbf{B2}}$$

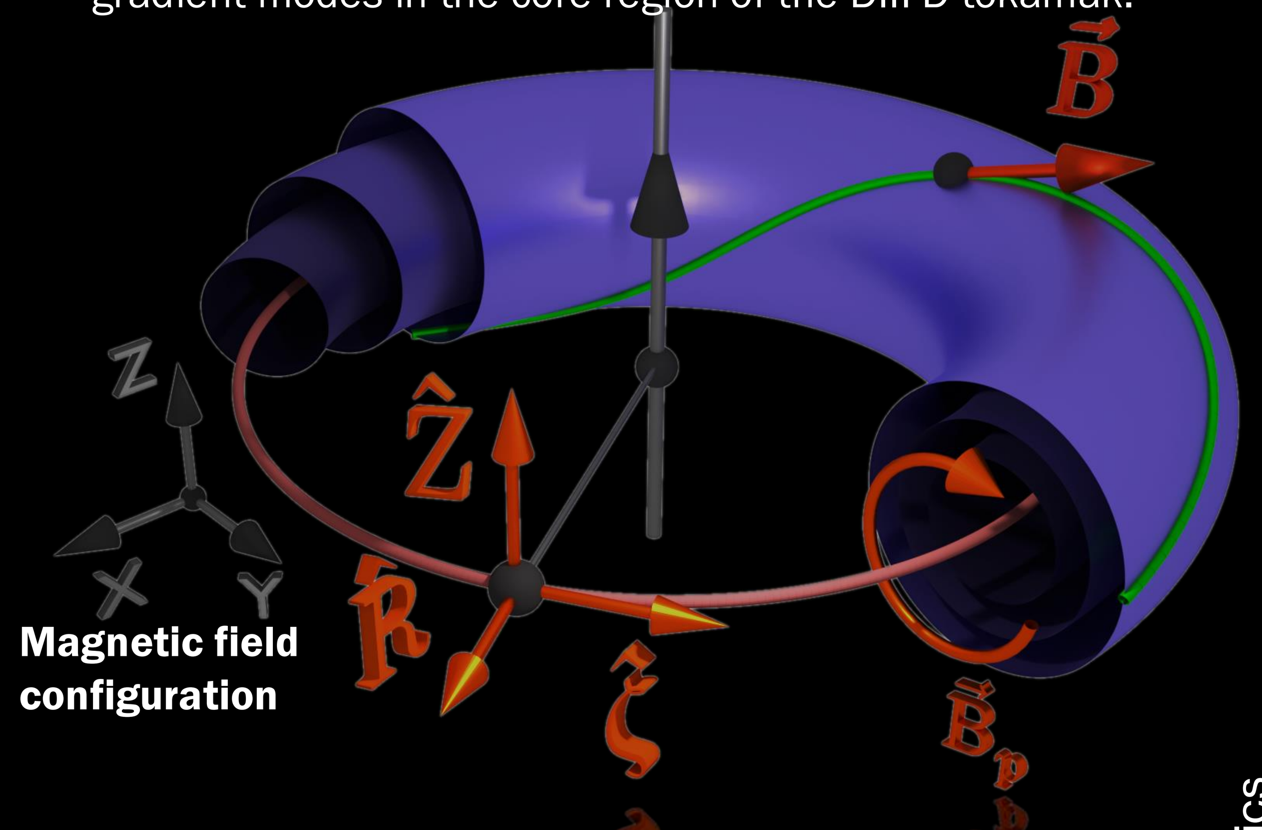
$$O_i = \sum_j \{W2_{ij}\,\tanh(\sum_k [W1_{jk}\,X_k] + B1_j)\} + B2_i$$

$$E = Error = (\underline{\mathbf{O}} - \underline{\mathbf{T}})^2 = (\underline{\mathbf{O}} - \underline{\mathbf{T}}).(\underline{\mathbf{O}} - \underline{\mathbf{T}}) = \sum_i (O_i - T_i)^2$$

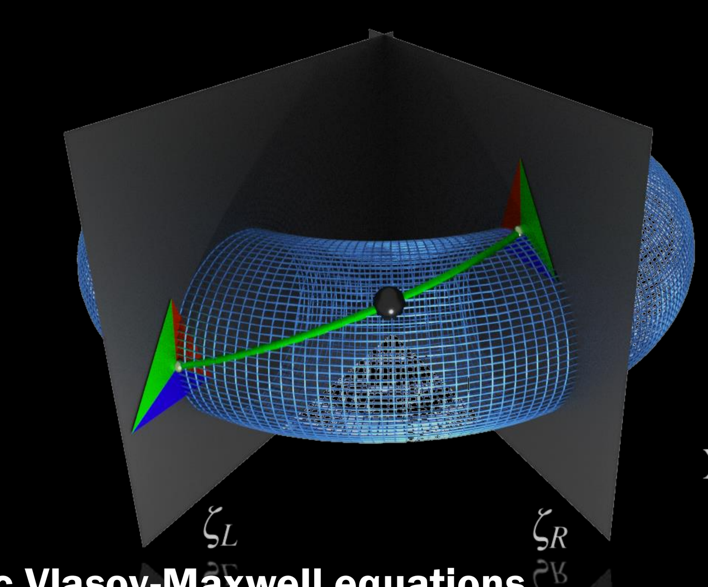
$$\underline{\mathbf{W1}} \rightarrow \underline{\mathbf{W1}} - \eta\ \partial E/\partial \underline{\mathbf{W1}}$$
$$\underline{\mathbf{W2}} \rightarrow \underline{\mathbf{W2}} - \eta\ \partial E/\partial \underline{\mathbf{W2}}$$
$$\underline{\mathbf{B1}} \rightarrow \underline{\mathbf{B1}} - \eta\ \partial E/\partial \underline{\mathbf{B1}}$$
$$\underline{\mathbf{B2}} \rightarrow \underline{\mathbf{B2}} - \eta\ \partial E/\partial \underline{\mathbf{B2}}$$

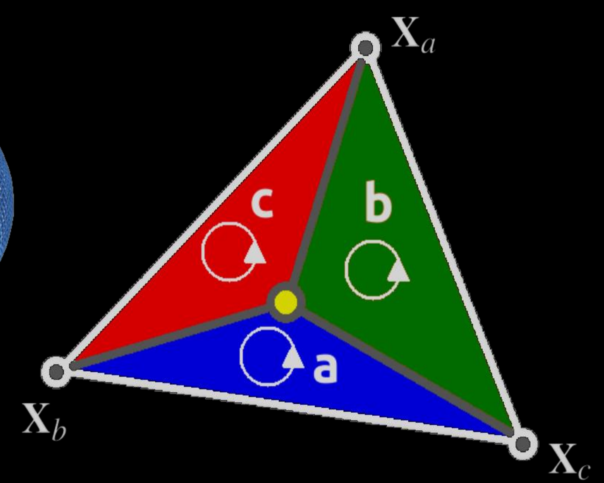
**A neural network integrator is trained using stochastic gradient descent to estimate the field lines (Right panel: estimation erorr)**

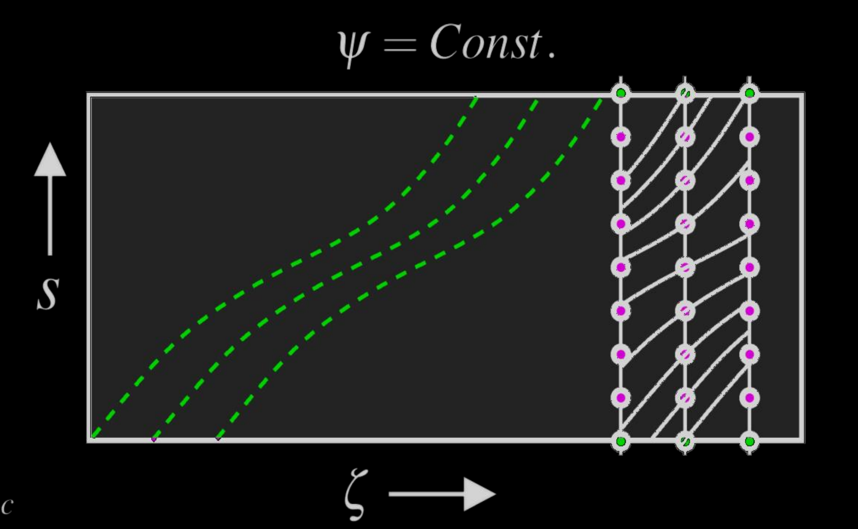



Magnetic field configuration




**Gyrokinetic Vlasov-Maxwell equations**

**(Linear-, adiabatic electron-, gyrokinetic ion-, electrostatic- case)**

**Benchmarking ITG mode in DIII-D [Shot # 158103]**

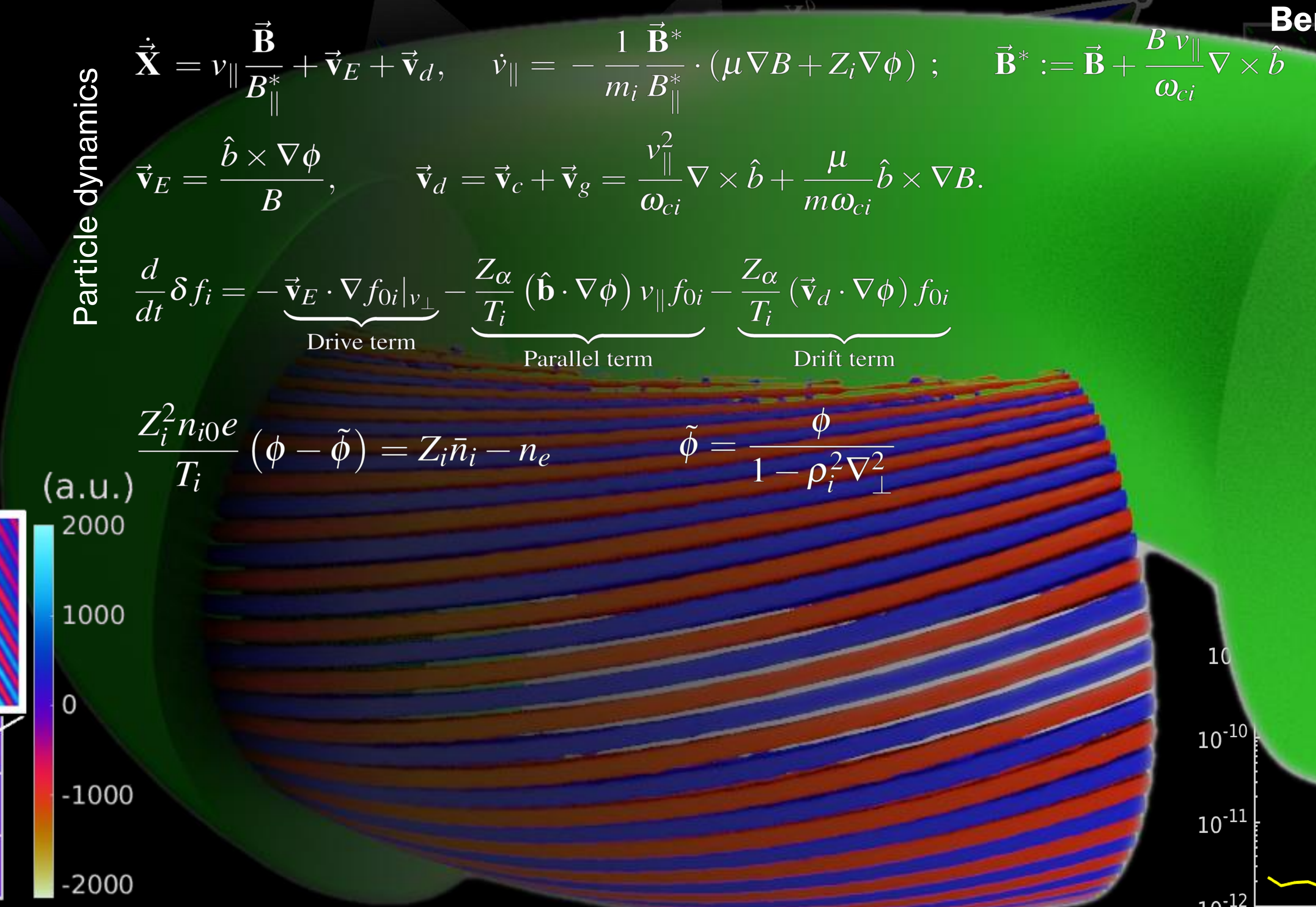
Particle dynamics

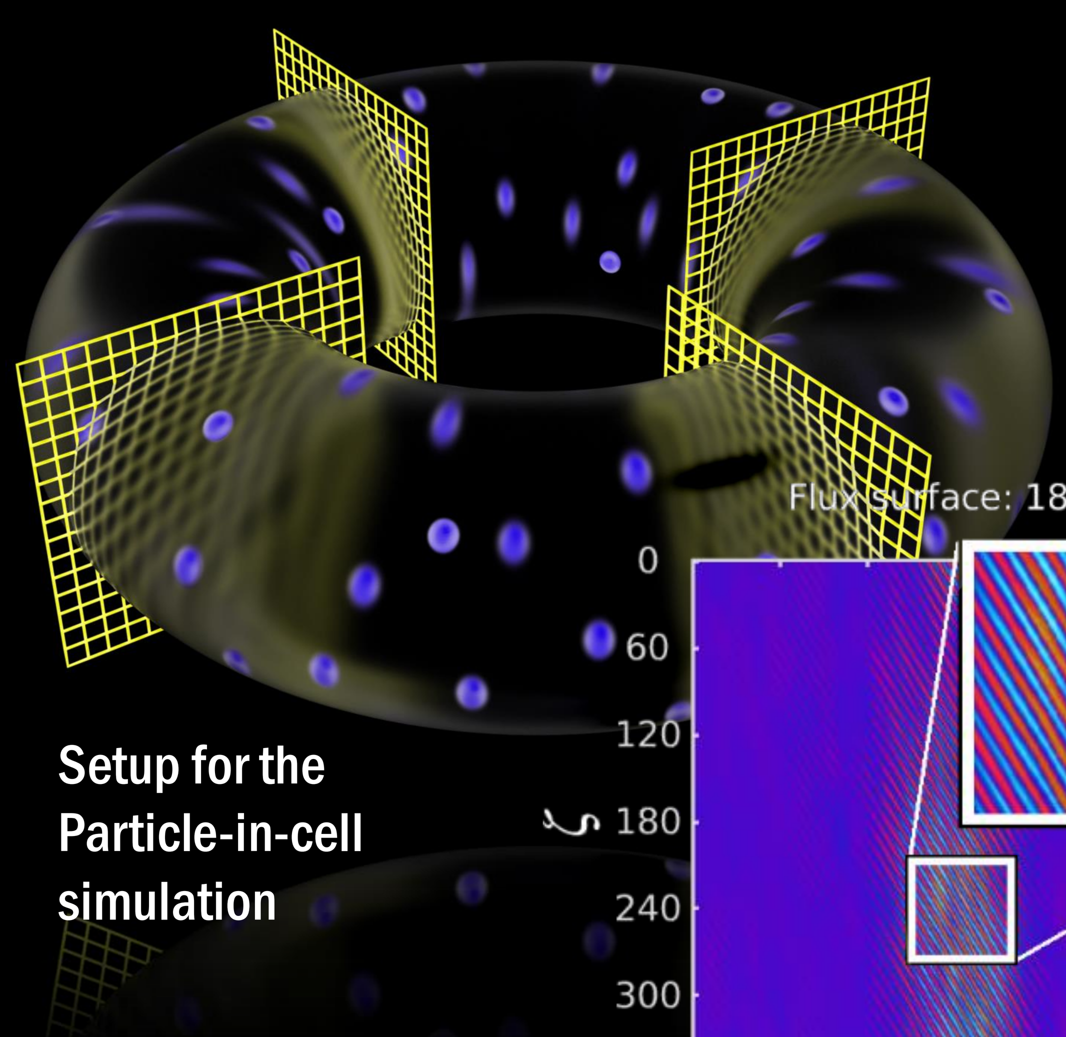
$$\dot{\vec{\mathbf{X}}} = v_\parallel \frac{\vec{\mathbf{B}}}{B_\parallel^*} + \vec{\mathbf{v}}_E + \vec{\mathbf{v}}_d, \quad \dot{v}_\parallel = -\frac{1}{m_i}\frac{\vec{\mathbf{B}}^*}{B_\parallel^*}\cdot(\mu\nabla B + Z_i\nabla\phi)\ ; \quad \vec{\mathbf{B}}^* := \vec{\mathbf{B}} + \frac{B v_\parallel}{\omega_{ci}}\nabla\times\hat{b}$$

$$\vec{\mathbf{v}}_E = \frac{\hat{b}\times\nabla\phi}{B}, \qquad \vec{\mathbf{v}}_d = \vec{\mathbf{v}}_c + \vec{\mathbf{v}}_g = \frac{v_\parallel^2}{\omega_{ci}}\nabla\times\hat{b} + \frac{\mu}{m\omega_{ci}}\hat{b}\times\nabla B.$$

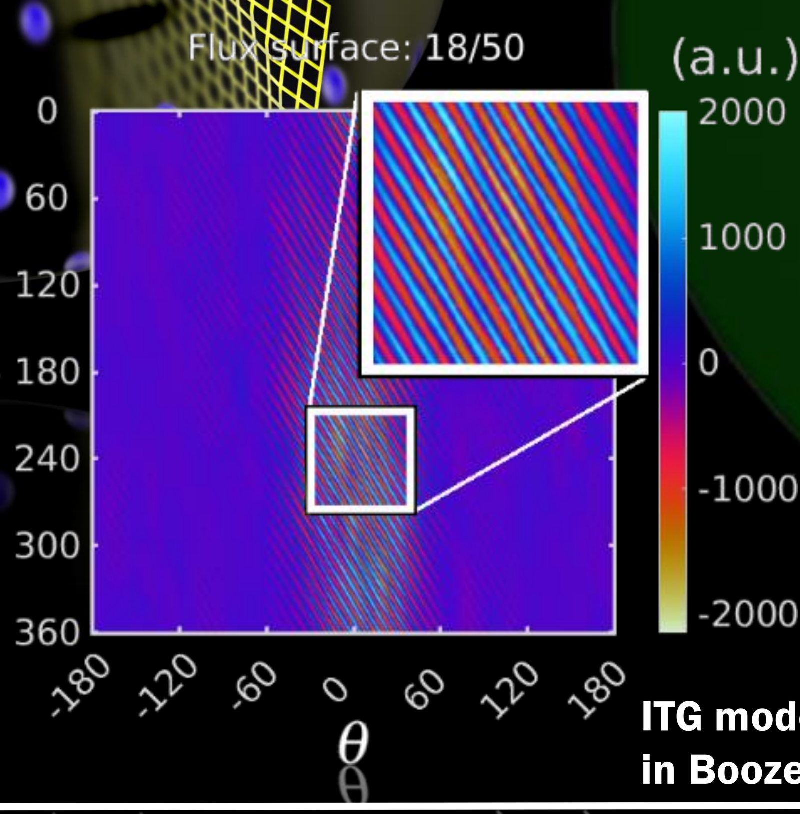
$$\frac{d}{dt}\delta f_i = \underbrace{-\vec{\mathbf{v}}_E\cdot\nabla f_{0i}|_{v_\parallel}}_{\text{Drive term}} - \underbrace{\frac{Z\alpha}{T_i}(\hat{\mathbf{b}}\cdot\nabla\phi)\,v_\parallel f_{0i}}_{\text{Parallel term}} - \underbrace{\frac{Z\alpha}{T_i}(\vec{\mathbf{v}}_d\cdot\nabla\phi)\,f_{0i}}_{\text{Drift term}}$$

$$\frac{Z_i^2 n_{i0} e}{T_i}(\phi - \tilde{\phi}) = Z_i\bar{n}_i - n_e \qquad \tilde{\phi} = \frac{\phi}{1-\rho_i^2\nabla_\perp^2}$$

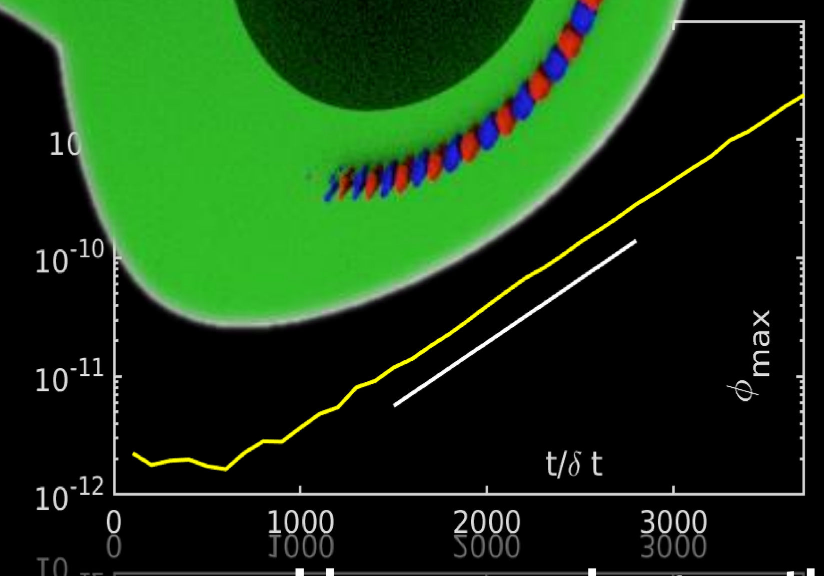




Setup for the Particle-in-cell simulation

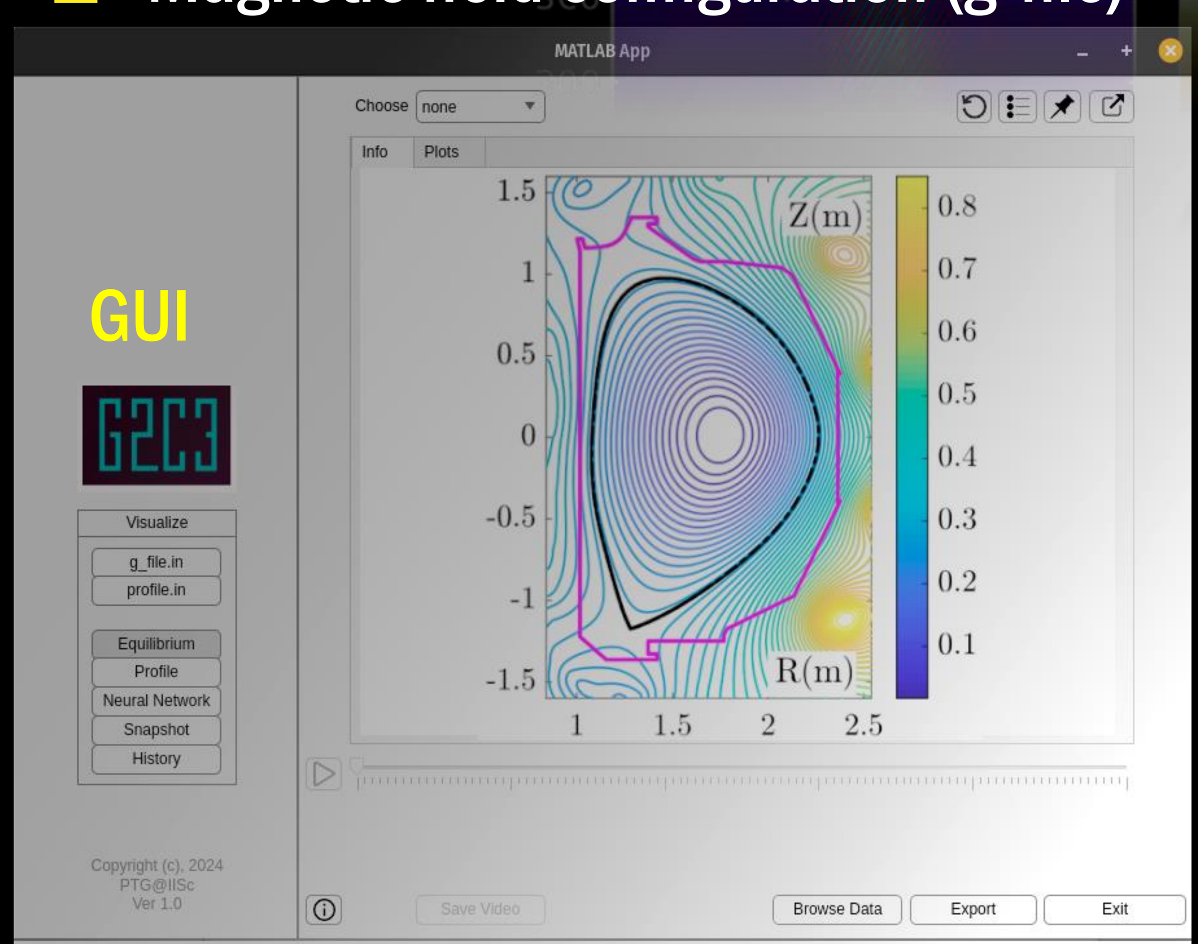



**ITG mode on a flux surface in Boozer coordinate**

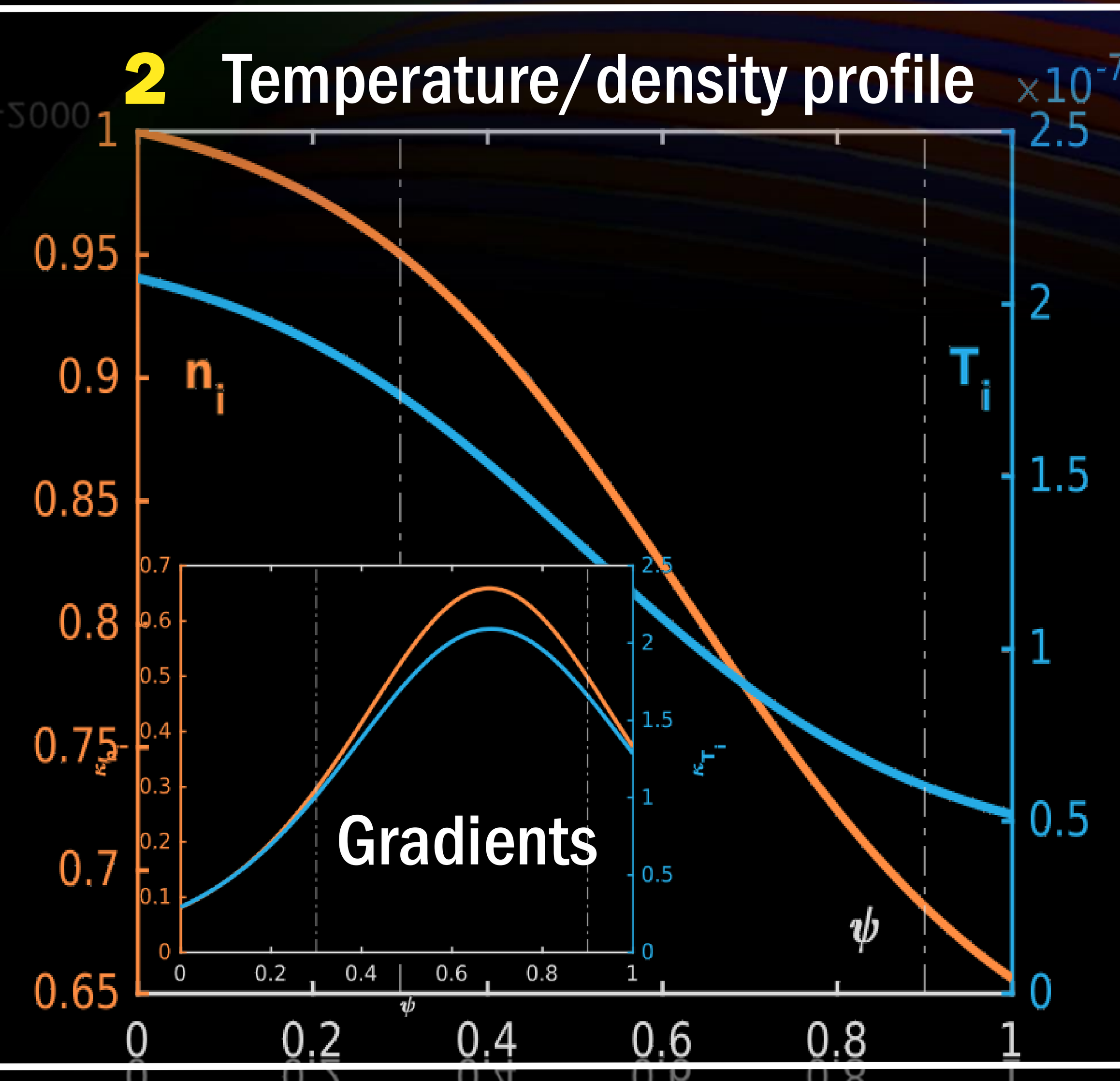



Linear mode growth

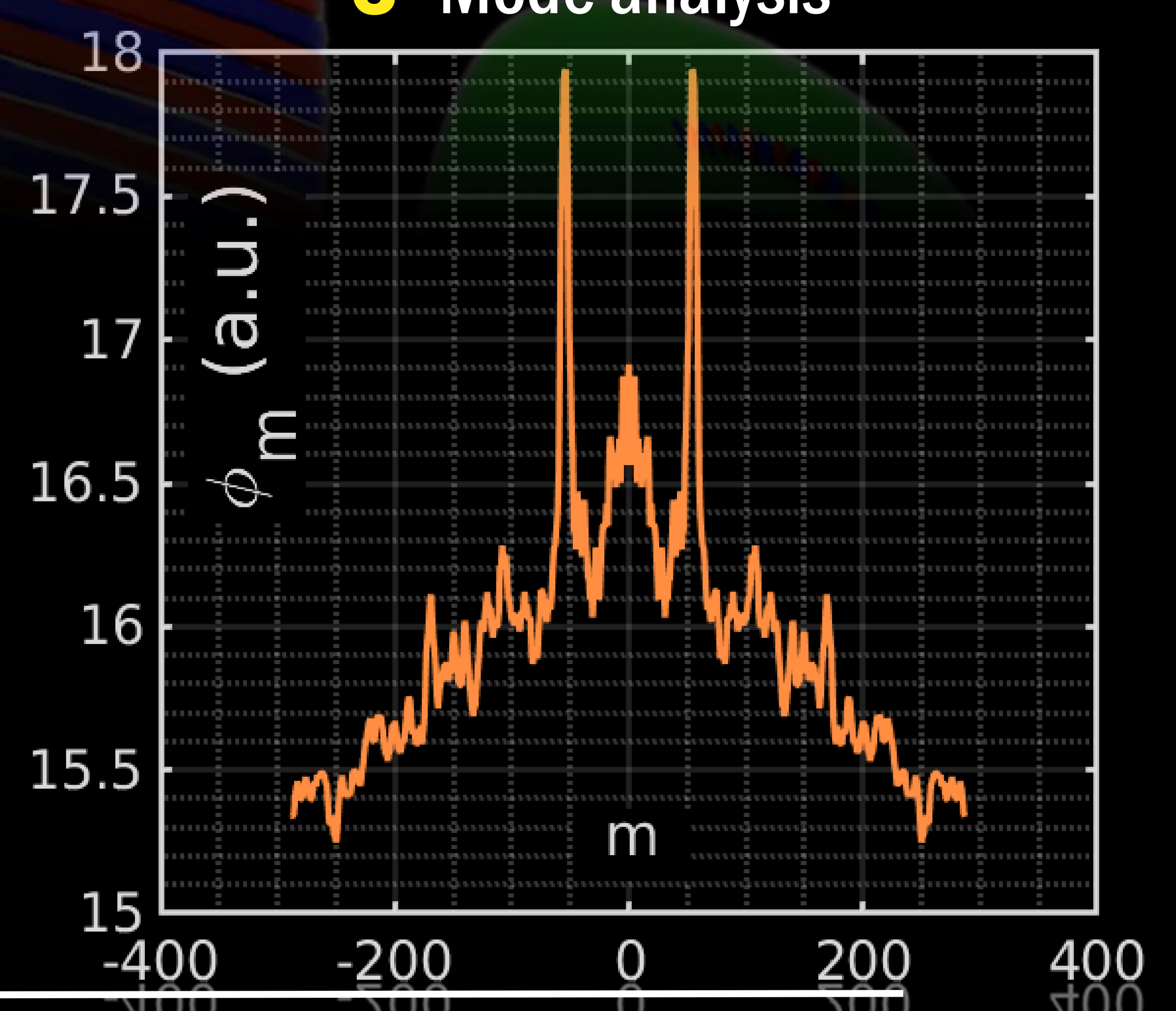
## 1 Magnetic field configuration (g-file)




## 2 Temperature/density profile




## 3 Mode analysis

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arXiv > physics > arXiv:2408.12851

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