Scrape-off layer simulations in a Double Null magnetic configuration

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The GBS Model

- The GBS Code simulates edge and SOL turbulent dynamics over a 3D domain *[Halpern et al., JCP 2016], [Ricci et al. PPCF 2012]*
- GBS evolves the drift-reduced Braginskii equations with ordering $k_\parallel \ll k_\perp$ and $d/dt \ll \omega_{ci}$. *[Zeiler et al., PoP 1997]*
- Magnetic pre-sheath boundary conditions are used for the outer boundary. *[Loizu et al., PoP 2012.]*

$$\frac{\partial n}{\partial t} = -\frac{1}{B}\frac{R_0}{\rho_{s0}}[\phi,n] + \frac{2}{B}\Big[C(p_e) - nC(\phi)\Big] - \nabla_\parallel(n v_{\parallel e}) + D_n\nabla_\perp^2 n + S_n$$

$$\frac{\partial \omega}{\partial t} = -\frac{1}{B}\frac{R_0}{\rho_{s0}}[\phi,\omega] - v_{\parallel i}\nabla_\parallel\omega + \frac{B^2}{n}\nabla_\parallel j_\parallel + \frac{2B}{n}C(p_e+\tau p_i) + \frac{B}{3n}C(G_i) + D_\omega\nabla_\perp^2\omega$$

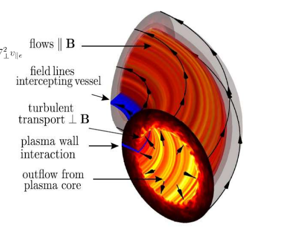
$$\frac{\partial v_{\parallel e}}{\partial t} = -\frac{1}{B}\frac{R_0}{\rho_{s0}}[\phi,v_{\parallel e}] - v_{\parallel e}\nabla_\parallel v_{\parallel e} + \frac{m_i}{m_e}\Big(\nu j_\parallel + \nabla_\parallel\phi - \frac{1}{n}\nabla_\parallel p_e - 0.71\nabla_\parallel T_e - \frac{2}{3n}\nabla_\parallel G_e\Big) + D_{v_{\parallel e}}\nabla_\perp^2 v_{\parallel e}$$

$$\frac{\partial v_{\parallel i}}{\partial t} = -\frac{1}{B}\frac{R_0}{\rho_{s0}}[\phi,v_{\parallel i}] - v_{\parallel i}\nabla_\parallel v_{\parallel i} - \frac{1}{n}\nabla_\parallel(p_e-\tau p_i) - \frac{2}{3n}\nabla_\parallel G_i + D_{v_{\parallel i}}\nabla_\perp^2 v_{\parallel i}$$

$$\frac{\partial T_e}{\partial t} = -\frac{1}{B}\frac{R_0}{\rho_{s0}}[\phi,T_e] - v_{\parallel e}\nabla_\parallel T_e + \frac{4}{3}\frac{T_e}{B}\Big[\frac{7}{2}C(T_e) + \frac{T_e}{n}C(n) - C(\phi)\Big] + D_{T_e}\nabla_\perp^2 T_e + \chi_{\parallel e}\nabla_\parallel^2 T_e + \frac{2}{3}T_e\Big[0.71\nabla_\parallel v_{\parallel i} - 1.71\nabla_\parallel v_{\parallel e} + 0.71(v_{\parallel i}-v_{\parallel e})\frac{\nabla_\parallel n}{n}\Big] + S_{T_e}$$

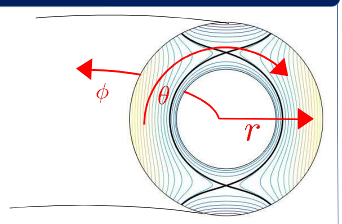
$$\frac{\partial T_i}{\partial t} = -\frac{1}{B}\frac{R_0}{\rho_{s0}}[\phi,T_i] - v_{\parallel i}\nabla_\parallel T_i + \frac{4}{3}\frac{T_i}{B}\Big[C(T_e) + \frac{T_e}{n}C(n) - C(\phi)\Big] + \frac{2}{3}T_i(v_{\parallel i}-v_{\parallel e})\frac{\nabla_\parallel n}{n} - \frac{2}{3}T_i\nabla_\parallel v_{\parallel e} - \frac{10}{3}\frac{T_i}{B}C(T_i) + D_{T_i}\nabla_\perp^2 T_i + S_{T_i}$$

$$\omega = \nabla_\perp^2\phi\,,\quad [\phi,f] = \vec{b}\cdot(\nabla\phi\times\nabla f)\,,\quad C(f) = \frac{B}{2}\Big(\nabla\times\frac{\vec{b}}{B}\Big)\cdot\nabla f\,,\quad \vec{b} = \frac{\vec{B}}{B}$$



The GBS Code

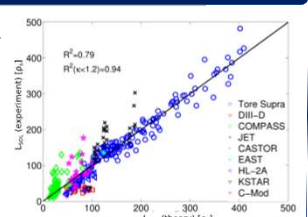
- Geometric coordinate system to avoid the coordinate singularity present for magnetic coordinates at the X-point.
- Flux-driven: no separation is made between equilibrium and fluctuating quantities.
- Plasma and heat outflow from the core mimicked by local plasma and heat sources and the code is evolved until a steady state is reached.
- 4th order finite differences for spatial derivatives and 4th order Runge-Kutta time stepping.



Magnetic flux surfaces and geometrical coordinate system.

Some of the past GBS achievements

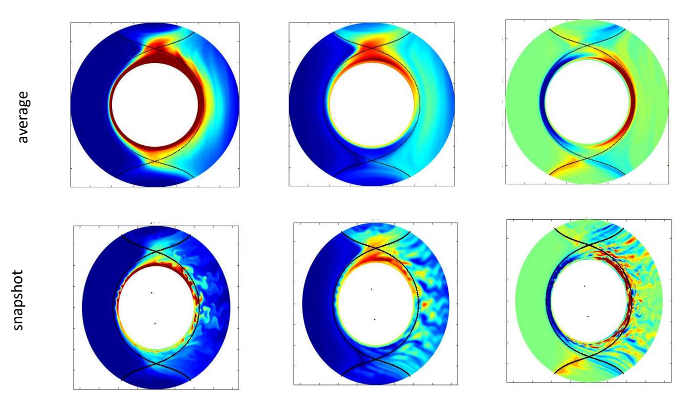
- Characterization of non-linear turbulent regimes in the SOL [Mosetto *et al.*, PoP 2015]
- SOL width scaling as a function of dimensionless/engineering plasma parameters [Halpern *et al.*, PPCF 2016]
- Origin and nature of intrinsic toroidal plasma rotation in the SOL [Loizu *et al.*, PoP 2014]
- Mechanisms regulating the SOL equilibrium electrostatic potential [Loizu *et al.*, PPCF 2013]



[Halpern *et al.*, PPCF 2016]

Double Null Simulation Results

- Magnetic equilibrium based on three current-carrying wires
- HFS is quiescent whilst LFS is turbulent.
- Pressure and electrical potential are higher at the upper than lower X point.
- High electrical potential at upper x point results in circulating flow.

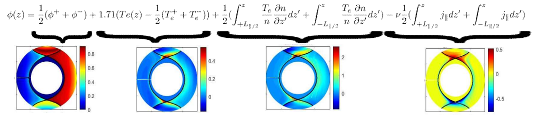


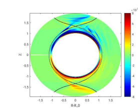
Electron pressure | Electrical potential | Parallel current

Up-Down Asymmetry

- Consider main terms in time and toroidally averaged Ohm's law, which is contained within the GBS $v_{||e}$ equation: $\nabla_\parallel\langle\phi\rangle = 1.71\nabla_\parallel\langle T_e\rangle - \langle\frac{T_e}{n}\nabla_\parallel n\rangle - \langle\nu j_\parallel\rangle$
- To obtain ϕ we integrate along the field lines, taking the mean of the integrals from either end of the field line:

$$\phi(z) = \frac{1}{2}(\phi^+ + \phi^-) + 1.71(Te(z) - \frac{1}{2}(T_e^+ + T_e^-)) + \frac{1}{2}\Big(\int_{+L_{\parallel/2}}^{z}\frac{T_e}{n}\frac{\partial n}{\partial z'}dz' + \int_{-L_{\parallel/2}}^{z}\frac{T_e}{n}\frac{\partial n}{\partial z'}dz'\Big) - \nu\frac{1}{2}\Big(\int_{+L_{\parallel/2}}^{z} j_\parallel dz' + \int_{-L_{\parallel/2}}^{z} j_\parallel dz'\Big)$$





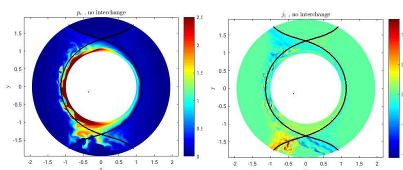
$C(p_e)$

- Simplified vorticity equation explains the form of the parallel current:

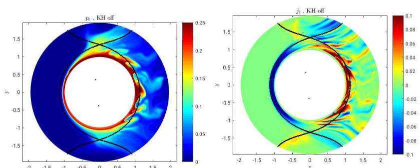
$$\nabla_\parallel j_\parallel = -\frac{2}{B}C(p_e)$$

Role of interchange and Kelvin-Helmholtz drive

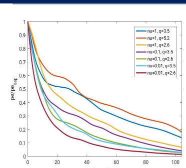
- Interchange instability drive – red circled terms – is removed.
- With drift-wave turbulence now dominant, HFS is more turbulent and the asymmetry is reversed.



- Kelvin-Helmoltz drive – green circled terms – is removed.
- Turbulence in upper part of HFS disappears
- Shape of turbulent structures on LFS changes.

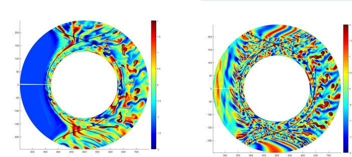


Parameter scan in resistivity and safety factor



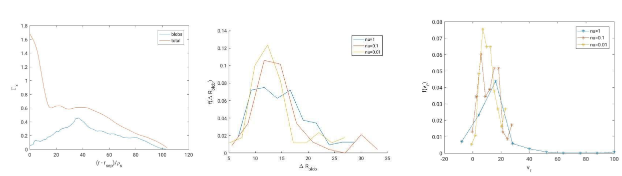
- The parallel resistivity, ν, varied by two orders of magnitude.
- Poloidal field strength (and hence safety factor *q*) also varied.
- The SOL width is increased with increased resistivity and higher *q* .

Blob transport



Blob recognition for ν = 1 (right) and ν = 0.01 (left)

- Blobs dominate transport in outer SOL
- Blobs are tracked via pattern recognition.
- At higher resistivity, blobs have greater radial size and velocity ….
- …. But are less numerous, resulting in similar level of blob transport



EUROfusion

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The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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