Mysteries of PEDESTAL poloidal ASYMMETRIES revealed

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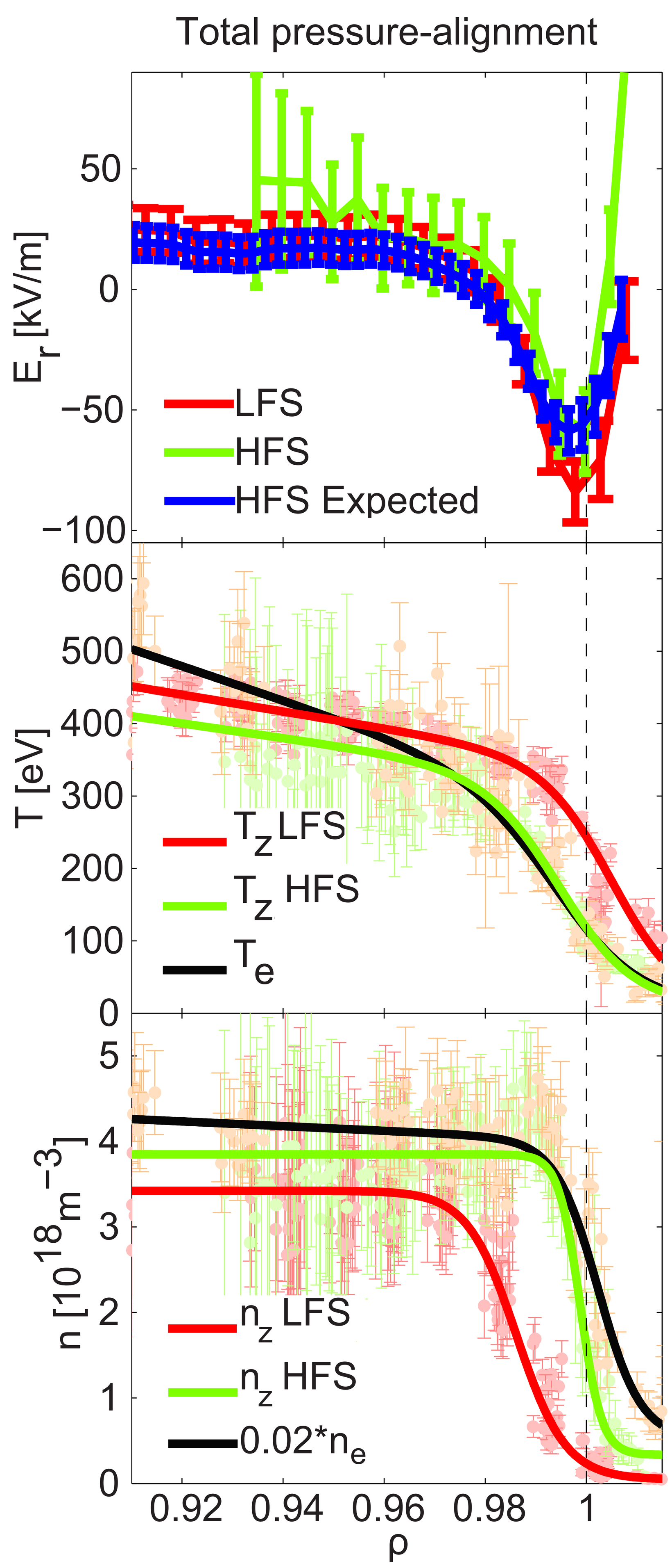
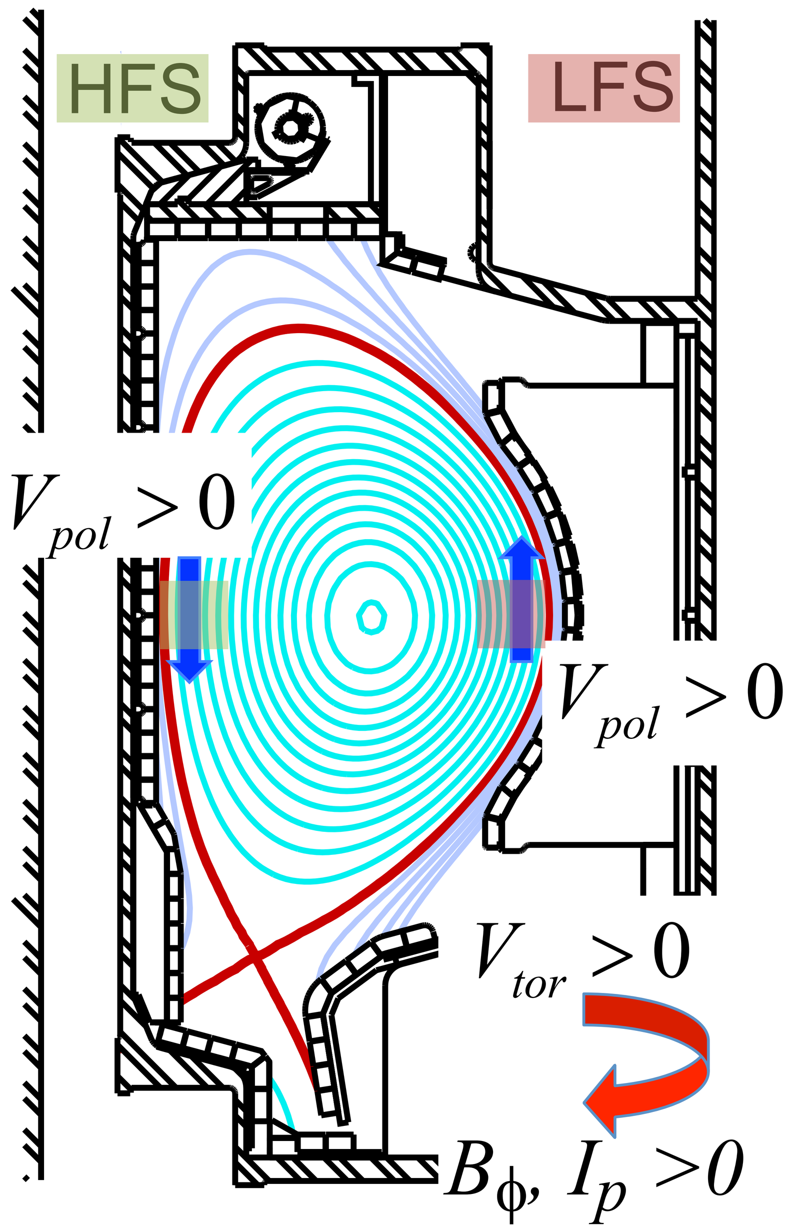
Poloidal asymmetries [1, 2] that standard neoclassical theory [3] cannot explain!



(Churchill 2014)



(Theiler 2014)

- Boron **temperature** larger on outboard (**LFS**) side compared to inboard (HFS) by up to 70%.
- HFS accumulation of boron **density** up to six fold, not simultaneously.

Is TURBULENCE needed to predict PEDESTAL FLOWS?

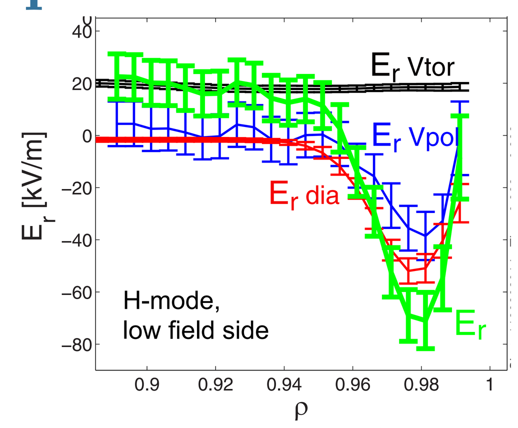
Predictive model for poloidal asymmetries at the edge pedestal

Main novel physics allowed in the model and implications

Novel physics allowed in the improved model:

1. **Sonic impurities** (strong $\mathbf{E}_r$)
2. **Strong diamagnetic flow effects**

$$\mathbf{E_r} = \frac{1}{Zen_z}\frac{\partial p_z}{\partial r} + V_{z,\mathrm{tor}}B_{\mathrm{pol}} - V_{z,\mathrm{pol}}B_{\mathrm{tor}}$$



(Theiler 2014)

Conservation equations for impurities:

- **Energy**:

$$\underbrace{\frac{n_z^2}{T_z^{\frac{1}{2}}}\mathbf{V}_z\cdot\nabla\left(\frac{T_z^{\frac{3}{2}}}{n_z}\right)}_{\text{Compressional heating}} + \underbrace{\cancel{\nabla\cdot\mathbf{q}_z}}_{\text{Div.heat flux}} = -\underbrace{\cancel{\pi_z:\nabla\mathbf{V}_z}}_{\text{Viscous}} - \underbrace{\frac{n_z\left(T_z - T_i\right)}{\tau_{zi}}}_{\text{Equilibration}}$$

- **Momentum**:

$$\underbrace{m_z n_z \mathbf{V}_z\cdot\nabla\mathbf{V}_z\cdot\mathbf{b}}_{\text{Inertial term}} + \underbrace{\cancel{\nabla_\parallel p_z}}_{\text{Press.grad.}} + \underbrace{\cancel{n_z ze\nabla_\parallel\phi}}_{\text{Pot.grad.}} + \underbrace{\cancel{\mathbf{b}\cdot(\nabla\cdot\pi_{\mathbf{z}})}}_{\text{Viscosity}} = \underbrace{R_{zi}}_{\text{Frict.}}$$

Non-dimensionalization:

$$\mathbf{V}_z = -cR^2\nabla\zeta\left(\frac{\partial\Phi}{\partial\psi} + \frac{1}{z_z e n_z}\frac{\partial p_z}{\partial\psi}\right) + \frac{K_z}{n_z}\mathbf{B}, \qquad K_z = K_z(\psi)$$

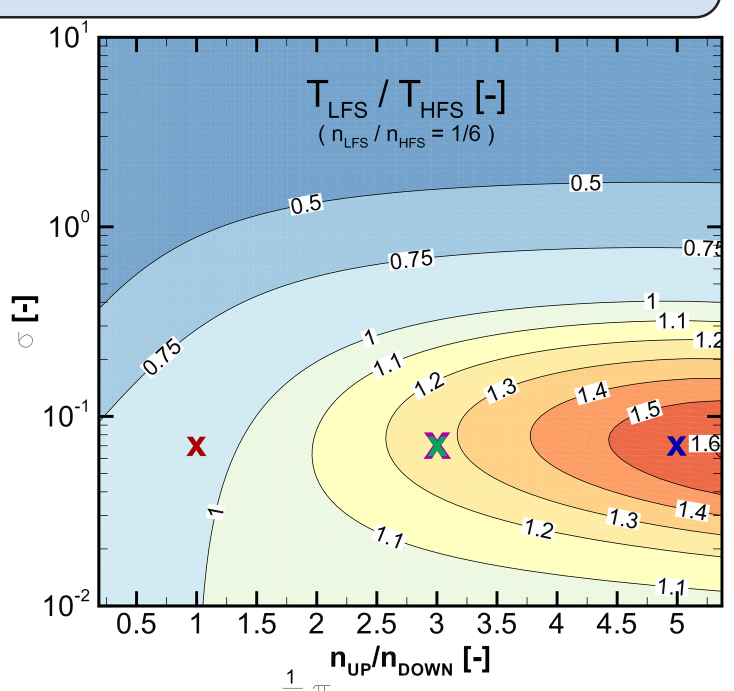
$$n \equiv \frac{n_z}{\langle n_z\rangle},\quad T \equiv \frac{T_z}{T_i},\quad b^2 \equiv \frac{B^2}{\langle B^2\rangle},\quad \sigma \equiv \frac{\tau_{zi}K_z\mathbf{B}\cdot\nabla\theta}{\langle n_z\rangle} \sim \frac{V_z^{pol}\tau_{zi}}{qR}$$

$$D \equiv \frac{cI\langle n_z\rangle}{K_z\langle B^2\rangle}\left(\frac{\partial\Phi}{\partial\psi} + \frac{1}{z_z e n_z}\frac{\partial p_z}{\partial\psi}\right) \sim \frac{V_z^{tor}}{V_z^{pol}},\quad V \equiv \frac{BV_{\parallel i}}{\frac{K_z\langle B^2\rangle}{\langle n_z\rangle}} \sim \frac{V_{\parallel i}}{V_z^{pol}}$$

Energy

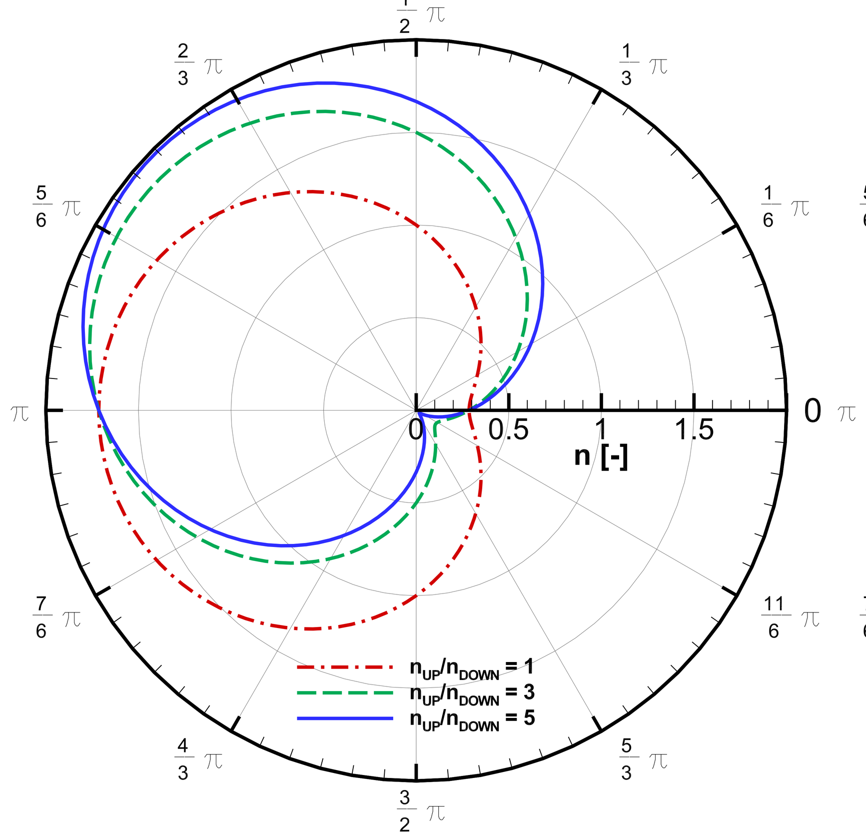
$$\boxed{\sigma\frac{\partial}{\partial\theta}\ln\left(\frac{T^{\frac{3}{2}}}{n}\right) = \frac{3}{2}\frac{n}{T}\left(1 - T\right)}$$

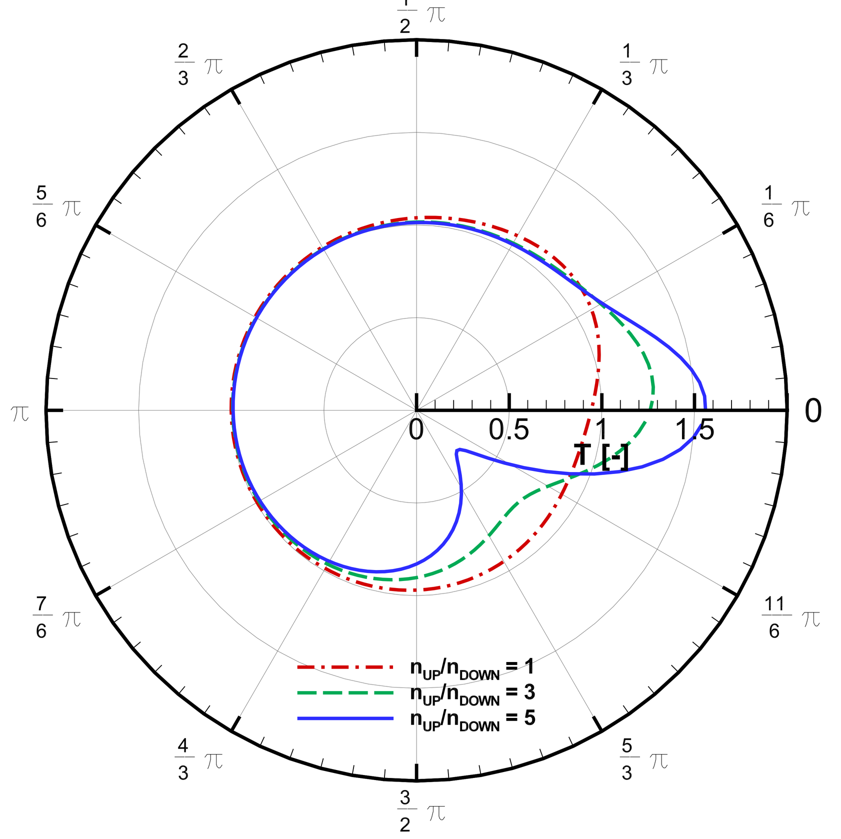
$$\overset{\sigma\ll 1}{\Rightarrow}\; T = 1 + \frac{2\sigma}{3n^2}\frac{\partial n}{\partial\theta} + O\left(\sigma^2\right)$$



Fourier decomposition:

$$n = 1 + c\cos\theta + s\sin\theta$$





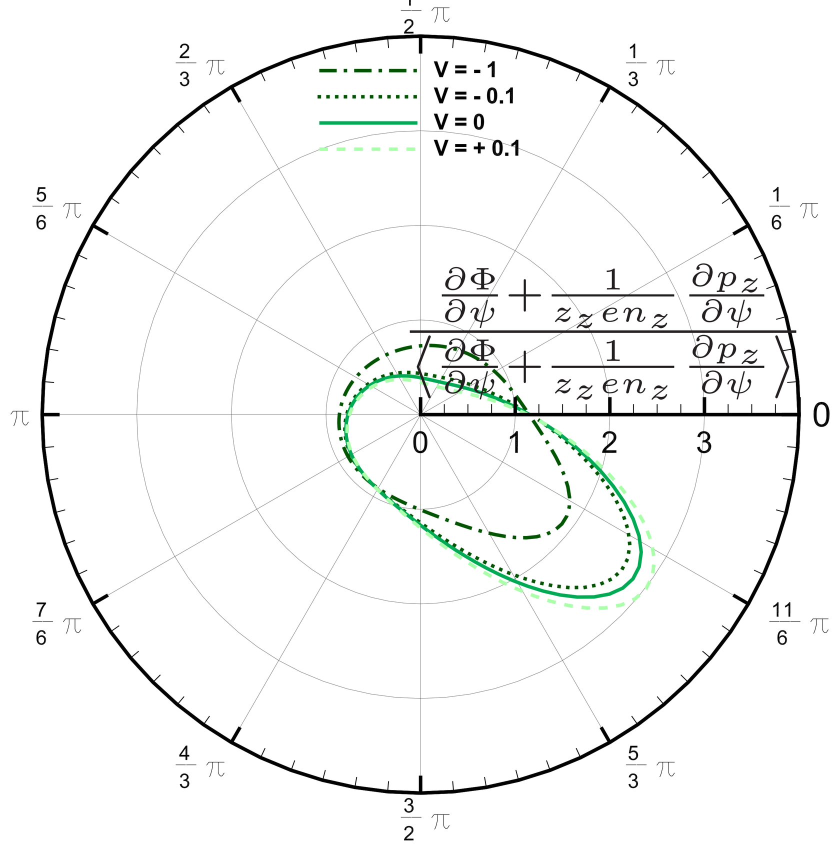
Momentum

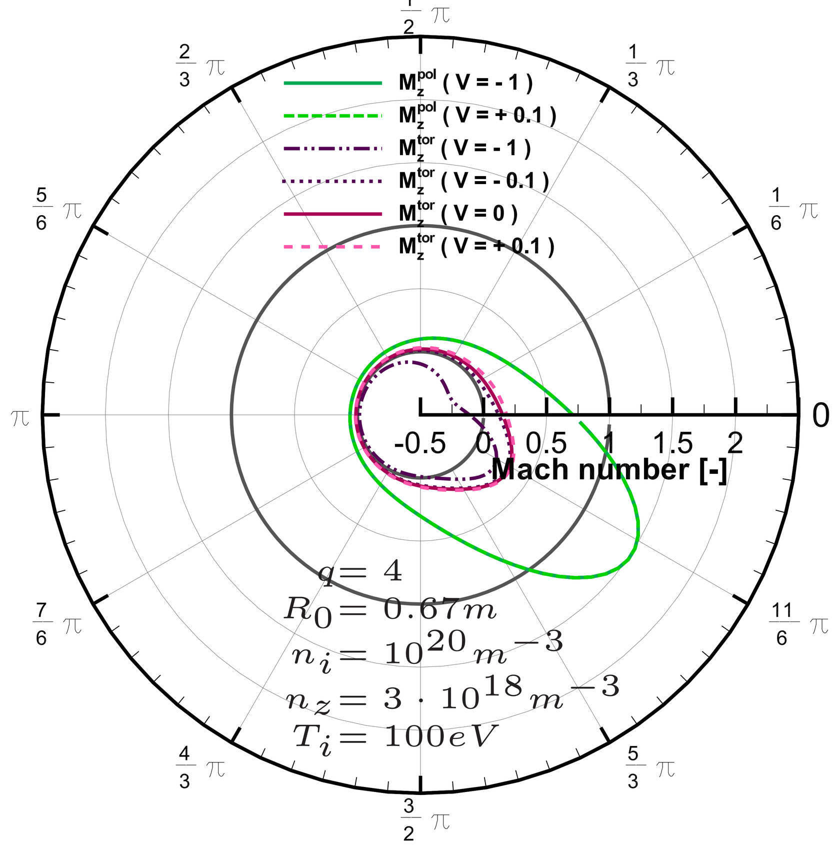
$$\boxed{0 = \frac{b^2}{n} - D - V + \sigma\frac{\partial}{\partial\theta}\left(\frac{b^2}{n^2} - \frac{D^2}{b^2}\right)}$$

Numerical solvers can be checked by analytical solutions:

$$\left\|\begin{array}{ll} n = \frac{b^2}{D}, & \text{if } V \text{ negligible} \\ n = \frac{b^2}{D+V}, & \text{if } \frac{V(2D+V)}{b^2} \text{ a flux function} \end{array}\right.$$

K_z, and thus flow, is obtained by flux surface averaging.





These extensions in neoclassical theory allow strong poloidal impurity temperature and density variation, providing a MORE REALISTIC MODEL FOR PEDESTAL OBSERVATIONS, WITHOUT INVOKING ANOMALOUS TRANSPORT.

References and acknowledgements

[1] C. Theiler et al., Nucl.Fusion 54,083017
[2] R.M. Churchill et al., Nucl.Fusion 53,122002
[3] P. Helander, Phys.Plasmas 5,3999
[4] G. Kagan et al., PPCF 52,055004

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