Two fluid drift-reduced Braginskii equations are solved for the plasma. Two assumptions: GBS code is linear from \( n_0 = 5 \times 10^{12} \) and \( n_0 = 5 \times 10^{13} \), respectively.

A refined two-point model is derived from the drift-reduced Braginskii equations

\[ v_f \cdot \nu_{\perp} (n_f) = S_{\text{GBS}} - n_{n_{\text{wall}}}(T_f) \]

with \( v_f \cdot \nu_{\perp} (n_f) = 0 \) and the assumptions

- \( v_f \) is linear from \( \nu_{\parallel} \rightarrow \nu_{\parallel} \)
- \( \nu_{\parallel} \) is tangential to the wall from \( \nu_{\parallel} \rightarrow \nu_{\parallel} \)
- Coaxial-shaped \( S_{\text{GBS}} \) and \( S_{\nu_{\parallel}} \)
- \( \nu_{\parallel} \) is decaying exponentially from \( \nu_{\parallel} \rightarrow \nu_{\parallel} \)
- Third input parameter, \( S_{\nu_{\parallel}} \), the total ionization source

In brief

- First fully turbulent SOL simulations self-consistently coupled to a kinetic neutral model implemented in GBS.
- Neutral kinetic equation with Krook operators for ionization, recombination and charge-exchange.
- Two fluid drift-reduced Braginskii equations are solved for the plasma.
- Development of a more refined two-point model in very good agreement with GBS.
- Initial study of gas puff imaging with fluctuating neutrals.
- The details of the model in [C. Wersal and P. Ricci, 2015 Nucl. Fusion 55 123014].

A model for neutral atoms in the SOL

Kinetic equation with Krook operators:

\[ \frac{d}{dt} \begin{pmatrix} f_{\parallel,0}(x,v) \\ f_{\perp,0}(x,v) \end{pmatrix} + \nabla \cdot \begin{pmatrix} j_{\parallel} \\ j_{\perp} \end{pmatrix} = -\mu_e \nabla \cdot \begin{pmatrix} f_{\parallel,0} \\ f_{\perp,0} \end{pmatrix} + \Gamma_{\text{kin}}(x,v) \]

Boundary conditions: particle conservation, i.e.

\[ \int_{\Omega} (f_{\parallel,0} + f_{\perp,0})(x,v) \, dv = \int_{\Omega} n_{\text{wall}}(x) \, dv \]

with \( r_{\text{out}} \) the ion and neutral particle outflow, \( \Gamma_{\text{kin}}(x,v) \) the velocity perpendicular to the wall. The distribution function of absorbed and re-emitted particles is \( f_{\text{abs}}(x,v) \), \( \omega_{\text{abs}}(x,v) \) the absorption frequency.

The method of characteristics:

The formal solution of Eq. (1) is

\[ T_v(x,v) = \int_{x_0}^{x} \frac{1}{v_f} \int_{v_0}^{v} \nabla g_{\text{abs}}(x,v) \, dv \, dx \]

An integral equation for neutral density is obtained by integrating Eq. (4) over \( v_f \).

\[ n_0(x,v) = \int dv T_f(x,v) = \int_{x_0}^{x} \frac{1}{v_f} \int_{v_0}^{v} \nabla g_{\text{abs}}(x,v) \, dv \, dx \]

The GBS code:

GBS is a 3D, flux-driven, global turbulence code in limited geometry. GBS solves the two fluid drift-reduced Braginskii equations (Picioli et al., PPCF 2013), \( \frac{d}{dt} \psi = m_i^2 \).

Neutral fluctuations and gas puff imaging

- Simulation with SOL and edge
- Gas puff from LFS
  - Small constant main wall recycling
  - \( n_0 = 2 \times 10^{13} \), \( T_{\text{wall}} = 200 \), \( q_p = 3.87 \), \( \rho_{\text{in}} = 500 \), \( \theta_{\text{in}} = 500 \), \( \rho_{\text{in}} = 10 \)
  - \( S_{\nu_{\parallel}} \), \( n_{\text{wall}}(T_f) \) is approximately proportional to light emission

Towards a simpler neutral model

Repeat a HFS gas puff simulation without neutral fluctuations:

- Left Average \( T_{\text{wall}}, \) and \( T_{\nu_{\parallel}} \)
  - no significant differences
- Right Average \( S_{\nu_{\parallel}} \) and neglect other neutral-plasma terms
  - large differences

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

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