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The influence of blob intermittency on fuelling

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Introduction

The overall performance in a tokamak is strongly affected by the dynamics in the edge and Scrape-Off Layer (SOL) regions. This region is characterized by the transition from closed to open magnetic field lines, and the last-closed-flux-surface (LCFS) defines the boundary between the confined plasma and the SOL region. The anomalous transport of heat and particles across the LCFS is strongly intermittent, and the plasma mainly escapes the confined region in field-aligned filaments (blobs) that are formed near the LCFS and propagate radially outwards.

The edge and SOL regions also contain a significant amount of neutral particles. The neutrals can either be puffed into the SOL for fuelling or diagnostic reasons, or originate from recycling of plasma on material surfaces. The presence of neutrals is known to affect the edge and SOL plasma through various interactions such as dissociation and ionization reactions, or charge-exchange collisions.

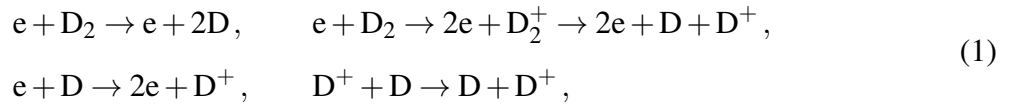
In this paper we present the results of a combined plasma-neutral model that allow for studying the effects of plasma turbulence and the associated transport on neutrals and vice versa. Both the plasma and neutral parts of the model are formulated in the fluid picture, which allow for studying the interactions between neutrals and turbulence self-consistently. In particular it is investigated how blobs affect the fuelling rate during gas-puffing at the outboard-midplane of a medium-sized tokamak.

Combined plasma-neutral model

A slab perpendicular to the magnetic field lines at the outboard-midplane is simulated in a model that describe the interactions between plasma and neutral particles in a self-consistent manner. The evolution of plasma fields is described by the HESEL model [1], which is a four-field drift-fluid model for the density, electron and ion pressures, and the vorticity. The HESEL model describes the edge and SOL dynamics, including the formation and propagation of field aligned filaments.

The neutrals are described in a three-fluid neutral diffusive model similar to that of [2], but with the difference that thermal molecules are now included. The three neutral fluids correspond to thermal deuterium molecules, deuterium atoms originating from dissociation of molecules and a hotter species of atoms that are created in charge-exchange collisions with hot ions. The

three species interact with the plasma and one another through the reactions



which are denoted dissociation and ionizing dissociation of molecules, and ionization and charge-exchange collision of atoms respectively.

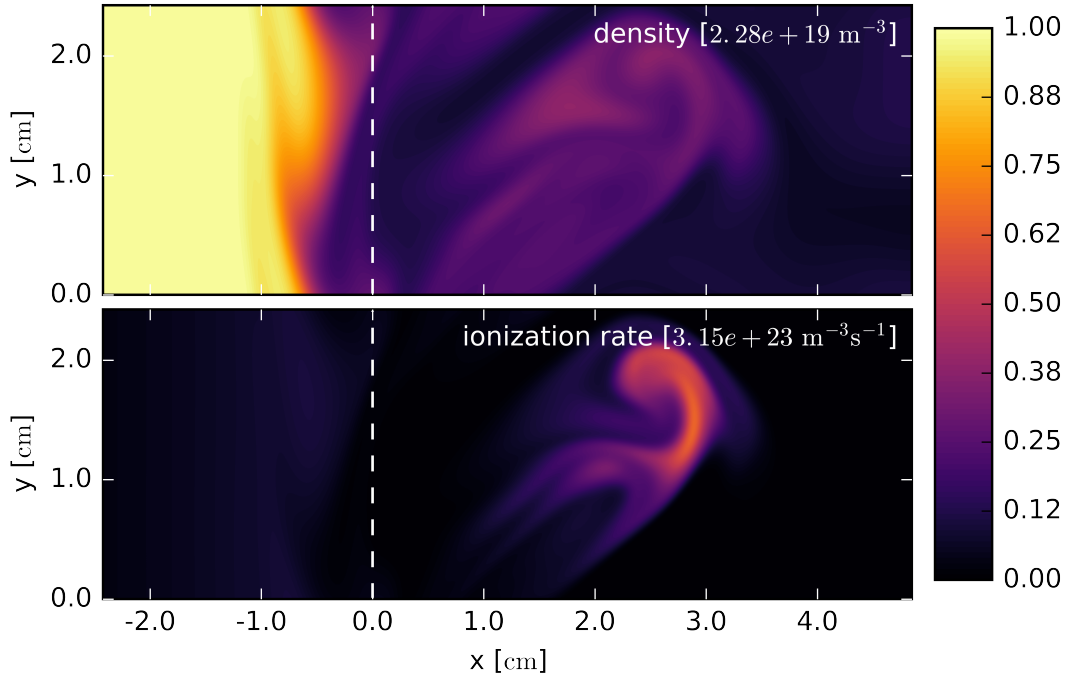


Figure 1: Density (upper), and ionization rate (lower) event calculated by the HESEL code. The area to the left of the LCFS (dashed vertical line) is the edge region, and that to the right of the LCFS is the SOL region. The domain as a slab perpendicular to the magnetic field lines at the outboard-midplane.

The interactions in (1) result in a set of fluid source terms. For the purpose of studying fuelling the source term of most interest is that for the density

$$S^n = n_e (n_n \langle \sigma_{iz} v \rangle + n_N \langle \sigma_{IZ} v \rangle), \quad (2)$$

where n_e is the electron density, n_n and $\langle \sigma_{iz} v \rangle$ are the neutral atom density and ionization reaction rate, and n_N and $\langle \sigma_{IZ} v \rangle$ are the neutral molecule density and ionization reaction rate. The reaction rates are non-linear functions of the electron temperature obtained from [3]. The density and the density source, i.e., the ionization rate, are shown for a blob event in Fig. 1.

Blobs and fuelling

The combined HESEL-neutral model is suitable for studying fuelling and ionization in edge and SOL regions with fluctuating plasma and neutral fields, since no approximations are made

to simplify the products in (2). It is of interest to assess to what degree neutrals penetrate the SOL region and thus fuel the plasma, as well as understand the effects that blob filaments have on the fuelling.

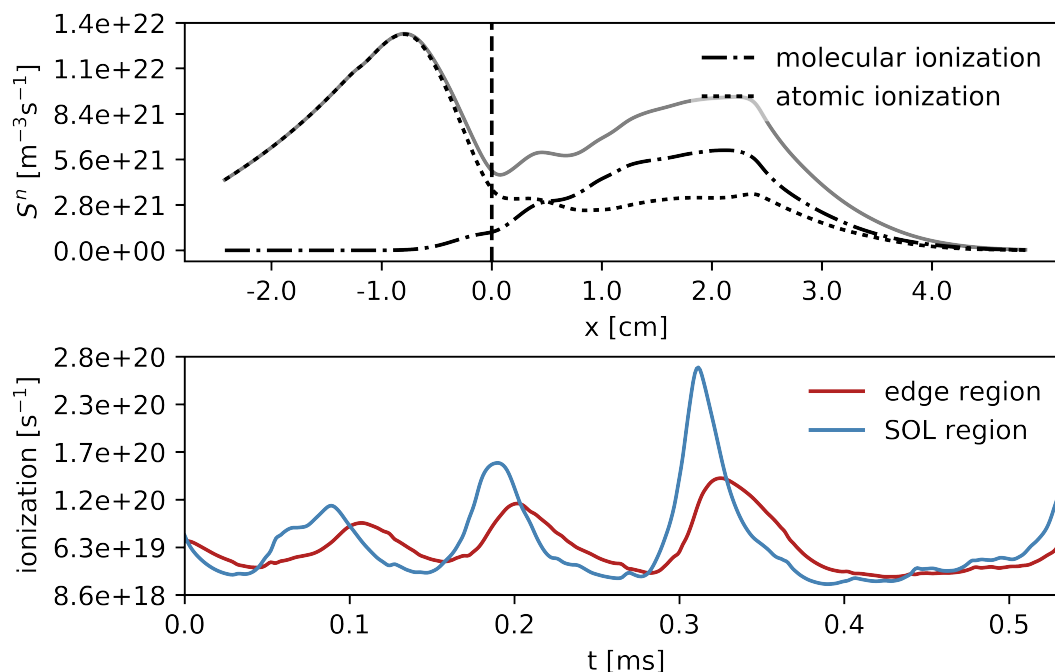


Figure 2: Time-averaged density source profile (upper), and integrated ionization in the edge and SOL regions as a function of time (lower). It is observed that the ionization level in the two regions is comparable, and that the ionization in the edge region, i.e., the fuelling, increases significantly following a blob event.

In Figure 2 the density source profile reveals that the edge and SOL regions experience a comparable amount of ionization. The main part of the ionization in the edge region is due to ionization of atoms, whereas the SOL ionization is dominated by ionizing dissociation of molecules.

The spatially integrated density source is a measure of the amount of ions and electrons created in ionization processes

$$\text{ionization} = \int dx dy S^n. \quad (3)$$

The ionization between the inner domain boundary and the LCFS is the main fuelling of the plasma, whereas electrons and ions created in SOL do not contribute directly to the fuelling. For the simulated domain the edge and SOL ionization is approximately equal.

It is observed from Fig. 2 that the SOL ionization is significantly increased when a blob emerges into the SOL region. This is in good agreement with the positive effect of the increased

pressure on the ionization reaction rate in (2). It is moreover observed that shortly after a blob event, the fuelling is likewise increased.

The increase in the fuelling rate can be explained by the neutral dynamics resulting from the increased electron pressure of the blob. During a blob event the ionization of both neutral atoms and molecules increase. The dissociation of molecules into atoms, and the number of charge-exchange collisions likewise increase. The fuelling is effectively unaffected by the ionization of molecules, since the edge is primarily fuelled by atoms, and since the density of molecules is much larger than that of atoms in the SOL, the blob creates more atoms than it ionizes. Due to their long mean-free path the atoms can penetrate the SOL and reach the edge region where they are ionized and thus contribute to fuelling.

Outlook

The results on the effects of blobs on fuelling were obtained from a combined plasma-neutral fluid model that include hot ions and treats the interactions between plasma and neutrals in a self-consistent way. Those features are thought to be essential to ongoing research in edge and SOL relevant experimentally observed phenomena such as shoulder formation [4] and the fuelling triggered H-mode density limit [5].

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