Impurity Transport Caused by Blob and Hole Propagations

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1. Introduction

The “blob” and the “hole” are the intermittent filamentary coherent structures along the magnetic field line in peripheral plasmas of fusion magnetic confinement devices. These structures are thought to be created from edge turbulences and to play an important role in the radial convective plasma transport in the scrape-off layer (SOL) [1].

Although many authors have investigated the blob dynamics on the basis of two-dimensional reduced fluid models [1, 2], kinetic effects in a blob are reduced to adjustable parameters under some assumptions in such fluid models. Thus, we have validated such assumptions with the first principles method, that is, the Particle-in-Cell (PIC) simulation, and confirmed that three-dimensional (3D) electrostatic PIC simulations provide an exact current closure for analysis of blob transports [3–5].

On the other hand, it has been pointed out that blob and hole propagations can induce impurity transport [1, 6]. However, numerical investigations regarding the impurity transport by the blob and hole propagations have not been conducted. Therefore, we have developed our particle simulation code to investigate dynamics between impurity and blob and hole structures.

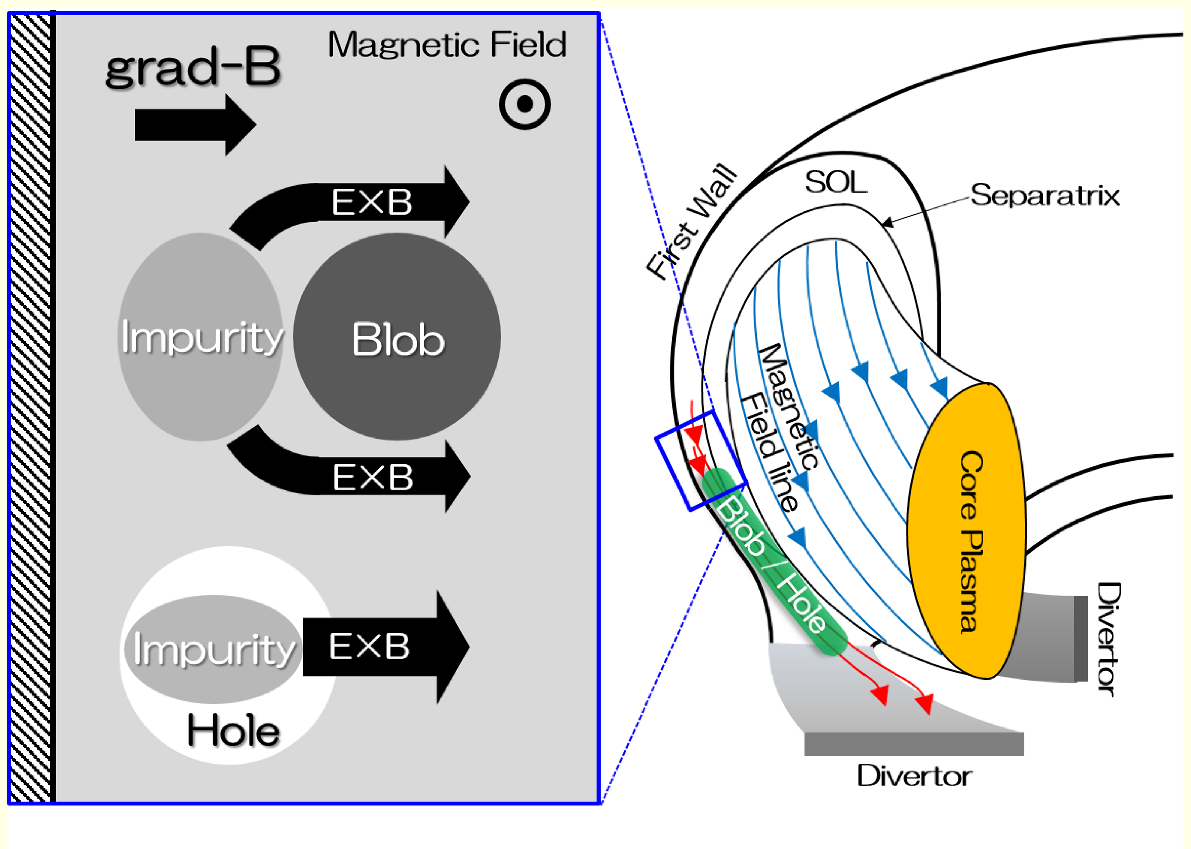

Figure 1: Schematic diagram of impurity transport by blob and hole propagations.

2. Configuration of the Simulation

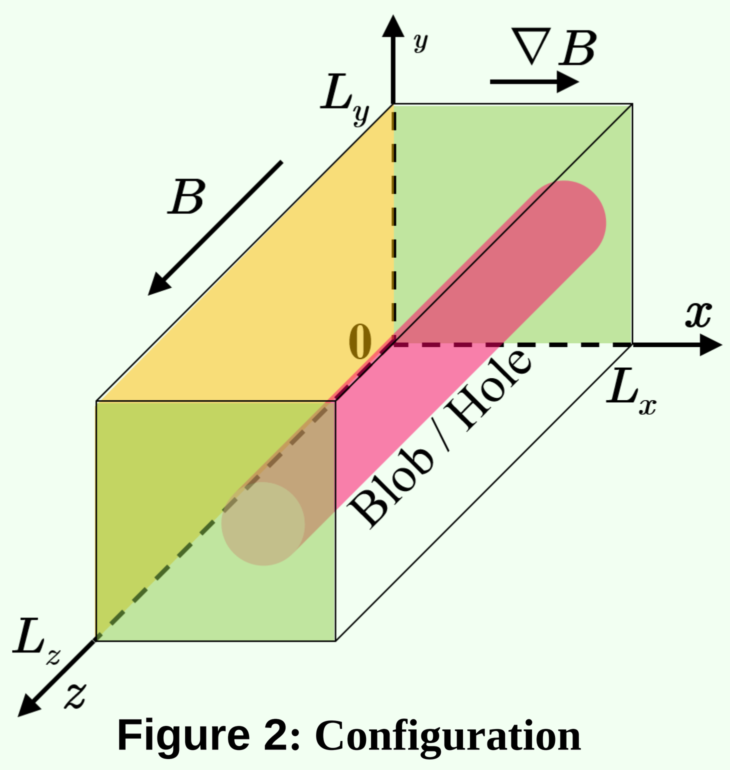

Figure 2: Configuration of the simulation.

At the boundary $x = 0$, particles are absorbed and $\phi = 0$.

Periodic boundary condition is applied in the y direction.

At the boundaries $z = 0$ and L_z, particles are absorbed and $\phi = 0$.

x: the radial direction. The plane at $x = 0$ corresponds to the first wall.
y: the poloidal direction.
z: the toroidal direction.

Both ends in the z direction correspond to the divertor plates.

Simulation Parameters

Grid spacing: $\Delta_g \approx 0.5\ \rho_s$ (where $\rho_s = c_s / \Omega_i$),

Mass ratio: $m_i / m_e = 100$, $m_{imp} / m_i = 4$ or 12,

Time step: $\Delta t \approx 1.25 \times 10^{-3}\ \Omega_i^{-1}$

Initial blob / hole size: $\delta_{bx} = \delta_{by} \approx 2\ \rho_s$.

System size: $L_x \times L_y \times L_z = 64\ \Delta_g \times 64\ \Delta_g \times 256\ \Delta_g$, or,
$64\ \Delta_g \times 64\ \Delta_g \times 2048\ \Delta_g$,

Magnetic field strength: $\Omega_i / \omega_{pi} = 0.5$ at $x = L_x$.

3. Results of Simulations

• Blob / Hole propagation with Uniformly Distributed Impurity

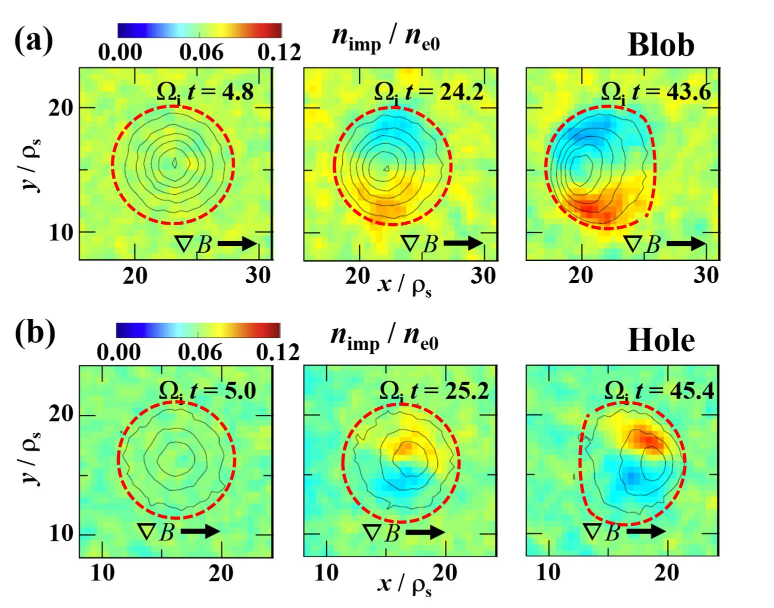

Figure 3: Distributions of impurity ion density in the x-y plane at $z = L_z / 2$ at various times.

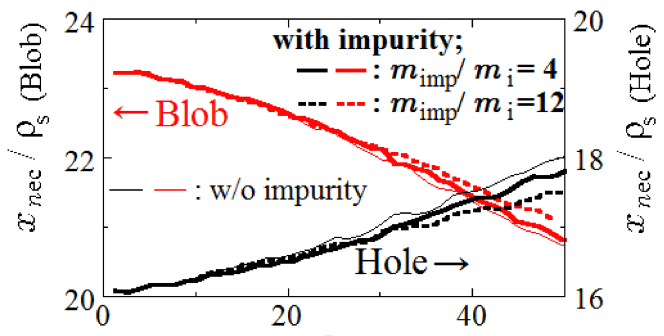

Figure 4: Evolution of the x position of the electron center of mass of the blob / hole with impurity / without impurity.

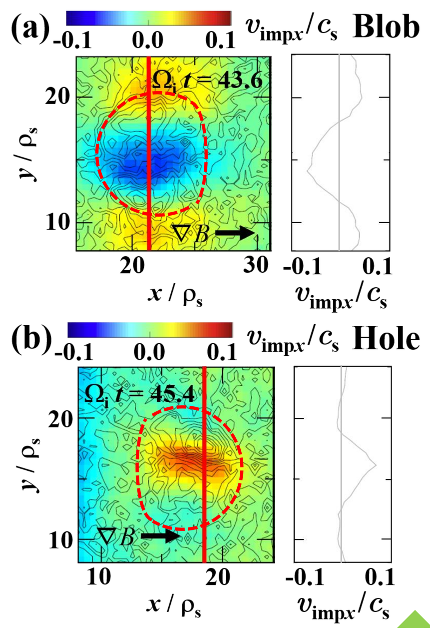

Figure 5: Distributions of the x components of impurity averaged velocity in the blob and the hole.

The biased density profile of impurity in the blob / the hole is formed by the polarization drift and propagates with the blob / the hole.

• Dynamics of Impurity in a Blob / a Hole Structure

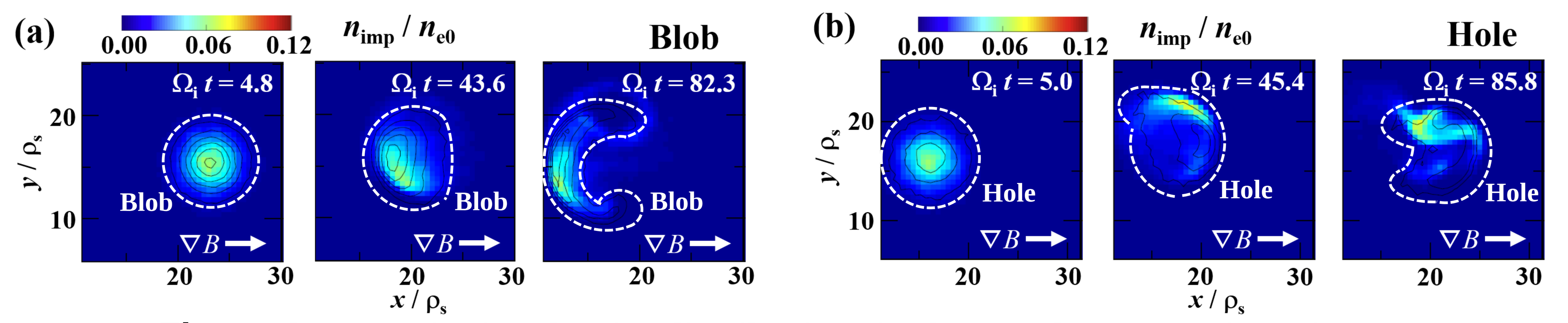

Figure 6: Impurity ion density distributions in the x-y plane at various times, where impurity ions are initially located in the blob (a) / the hole (b).

Most of impurity particles which stay in the blob / hole structure at initial stage are transported with the blob / the hole after shaping the biased profile.

• Impurity Transport by Blob / Hole Propagation

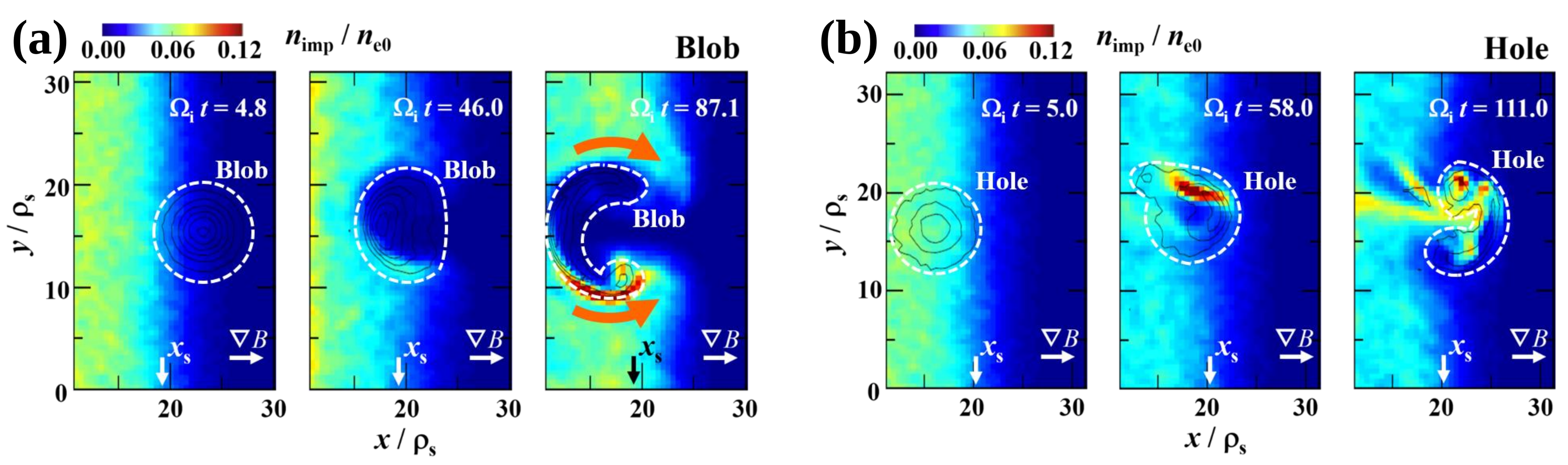

Figure 7: Impurity ion density distributions in the x-y plane at various times with the blob (a) / the hole (b) propagations, where the initial impurity density has a radial gradient.

The blob sweeps impurity ions. Impurity ions which surround the blob move in the grad-B direction. The effective radial diffusion coefficient at $x = x_s$ is obtained as $D_{imp} / D_B = 2.66$.

The hole moves from an impurity region and carries impurity ions in the grad-B direction. The effective radial diffusion coefficient at $x = x_s$ is obtained as $D_{imp} / D_B = 1.26$.

(Here D_B is the Bohm diffusion coefficient.)

4. Summary and Discussion

- We have developed a 3D-PIC code to study blob / hole dynamics with impurity.
- **We have showed the first demonstration of impurity dynamics with the blob / the hole propagation by the 3D-PIC simulation:**
  - The biased density profile of impurity in the blob / the hole is formed by the polarization drift.
  - Such a density profile propagates with the blob / the hole.
  - **The simulations in which the initial impurity density has a radial gradient have shown that the effective radial diffusion coefficient for impurity ions by a single blob / hole is comparable to the Bohm diffusion coefficient.**
- Discussion
  - The blob and hole propagation directions in helical devices are opposite to those on the low-field side in tokamak devices.

    ➡ Impurity transport by blobs / holes may be able to explain the difference of impurity transport property between tokamak and helical devices.

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