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Analysis of Impurity Clustering in the Edge Plasma of Tokamaks

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Confinement quality in fusion plasma is significantly influenced by the presence of heavy impurities, e.g. Tungsten, which can lead to radiative heat loss and reduced confinement. This study explores impurity transport modeled by inertial particles in edge plasma, a previously unexamined aspect in plasma physics, using high-resolution direct numerical simulations of the Hasegawa-Wakatani equations, modeling electrostatic drift-waves in edge plasma. Our simulations employ one-way coupling of one million inertial point impurity particles.

We observe that with Stokes number, which characterizes the inertia of particles, being zero, the impurity particles behave as fluid particles. They follow the fluid streamlines, acting as "passive tracers." This results in a uniform distribution of particles, with no significant clustering. As the Stokes number increases, the inertia of the particles begins to dominate, causing them to deviate from the fluid streamlines. This results in the preferentially concentration of impurities, leading to distinct clustering and void formation. When the Stokes number is significantly larger, the impurity particles' inertia is so high that they tend to resist changes in their motion due to the fluid. As a result, they tend to maintain their trajectory, moving in a more random fashion, resulting in less clustering and more dispersion.

The study calculates impurity velocity divergence using modified Voronoi tessellation, which assigns specific volumes to impurity particles. By determining volume changes, the impurity velocity divergence can be calculated. Positive divergence indicates void formation, while negative signifies clustering. As the Stokes number increases, the probability density function (PDF) of divergence widens, reflecting more clustering. However, beyond a certain point, the PDF narrows indicating reduced clustering. The study also examines a modified H-W model with pronounced zonal flow and finds that it substantially decreases the divergence.

Author: LIN, Zetao (Aix-Marseille Université)

Presenter: LIN, Zetao (Aix-Marseille Université)

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