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Modelling dust grain trajectories in MAST and ITER using plasma backgrounds from B2SOLPS5.0

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Introduction

Dust is produced in Tokamaks by various different processes, including arcing during disruptions and ELMs, and agglomeration. It is important to understand what effect the creation of dust in Tokamaks has on the long-term operation of the device. The dust poses problems both for safety and performance. For example, a significant fraction of the tritium inventory can be absorbed by dust, posing a radiological threat. Dust may be able to transport impurities around the scrape off layer (SOL), and perhaps even to the core plasma.

Carbon is chosen as a divertor material in most Tokamaks due to its excellent thermal properties. However, it readily reacts with hydrogen isotopes, and this increases chemical erosion yields. Dust characterisation studies have shown that carbon dust grain produced in Tokamaks are most often on the micron scale. Tungsten will also be used in the ITER divertor. Tungsten has very low sputtering yield, but can melt and blister under high thermal loads. Studies of tungsten divertors are currently underway.

Recently, there has been some interest in quantifying the effect of dust transport and the associated transport of impurities [1, 2]. We present here results from a dust transport code (DTOKS) developed by the authors.

The code calculates the charge, temperature and forces acting on a dust grain. To estimate the charge we use an adapted orbit motion limited (OML) equation, including secondary and thermionic electron emission yields. The currents of ions and electrons can then be calculated, and the heating and cooling mechanisms acting on the grain. These parts have been discussed in a previous publication [1]. We concentrate here on the dust equation of motion and present simulations using plasma backgrounds generated using B2SOLPS5.0.

Equation of Motion

Dust grains are charged, and are therefore are affected by external electric and magnetic fields according to the Lorentz force $q_d(\mathbf{E}+\mathbf{v}_d\times\mathbf{B})$, where q_d is the charge on the grain, and $\mathbf{v}_d$ is its velocity. This can be shown to increase as a^{-2}, where a is the dust radius, as the particle evaporates.

The flow of plasma around the dust particle exerts a drag force upon it. This drag force is usually separated into a number of components: neutral drag and ion drag, electron drag is ignored. We also ignore neutral drag because the concentration of neutrals outside the very edge of the plasma is small. We have an effective flow pressure due to plasma flow, or more specifically ion flow. Using the relative velocity $\mathbf{v}_p - \mathbf{v}_d$, the force on the particle is $\pi a^2 m_i n_0 |\mathbf{v}_p - \mathbf{v}_d| (\mathbf{v}_p - \mathbf{v}_d)$, where $\mathbf{v}_p$ is the plasma velocity, and we assume a cross-section of πa^2, rather than the OML cross-section. This is most accurate if the plasma is supersonic and any focussing of the ion flow is small.

Density and temperature gradients within the plasma are generally small over distances of the Debye length scale, and we can therefore ignore the pressure gradient force.

Gravity is usually small compared to the other forces mentioned in this section, but is included as it is important for the motion of large dust grains, or the motion of dust grains outside plasma regions.

The rocket force [2] requires a temperature gradient to be sustained by the particle, so that one side of the particle begins to ablate, and propels the particle in the opposite direction. A micron-sized grain cannot sustain a large enough temperature gradient. Therefore, we do not include it, but the importance for larger grains or non-spherical particles requires further work.

Plasma Background and Initial Conditions

It has been estimated theoretically that dust can reach speeds of 10-100 ms^{-1} by acceleration in the divertor region [2]. From IR camera data, it has been estimated the initial speed could even reach 10^3 ms^{-1}. We assume that dust enters the plasma from the outer divertor. Other injection points will be studied in future publications.

The plasma background used is B2SOLPS5.0 [3]. This is a three fluid plasma code based on the B2 model that is capable of generating data for the scrape off layer region of various Tokamaks. This enables us to study dust grain interaction with plasmas in both MAST and ITER.

Results

We begin with micron radius carbon dust injected at 10 ms^{-1} into MAST at various angles to the outer divertor plate. The dust trajectories in the poloidal and toroidal planes are shown in figure 1. We see that dust injected to the right of the vertical in the poloidal plane is accelerated in the plasma and ejected, leaving the plasma and travelling to the outer wall. As the initial trajectory is changed towards the x-point the dust travels further towards the core, eventually

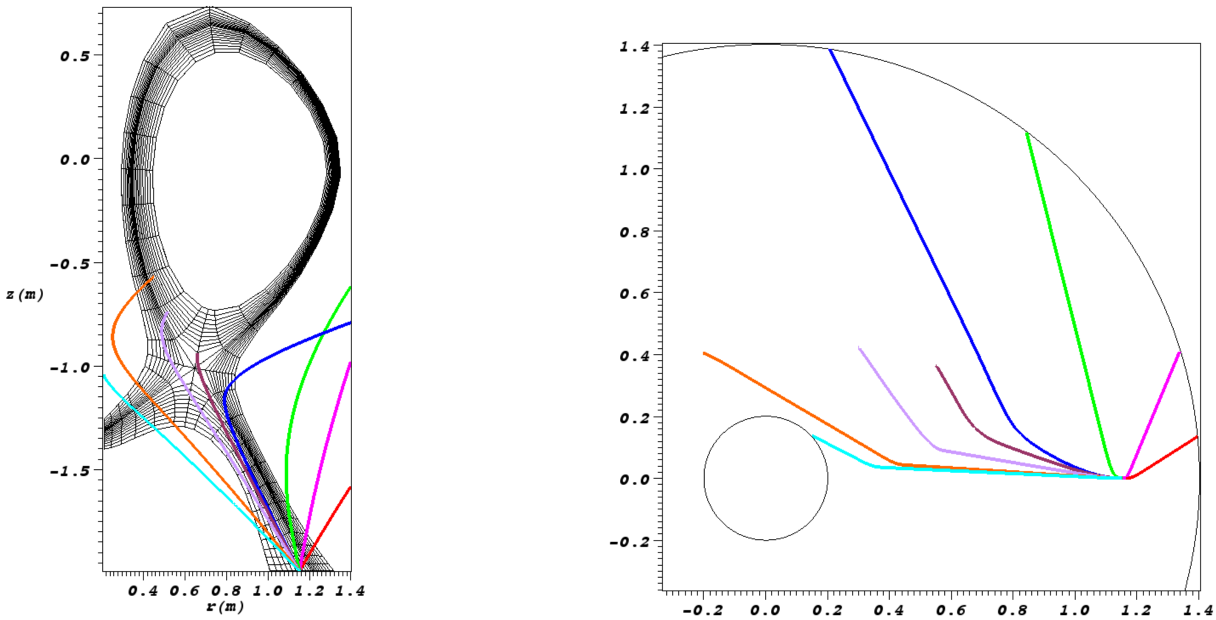

Figure 1: Micron radius graphite grains in MAST.

evaporating around the separatrix. Injected further towards the centre column, the particle can leave the plasma, travel around the centre column and re-enter the plasma. The particles can travel significantly toroidally. An important result is that the major acceleration mechanism while the particle is in the plasma is flow pressure.

We can generate a plot of the impurity deposition injecting particles at 0.1° increments in the poloidal plane, and summing up the mass evaporated in each cell. We weight the deposition of each particle by the cosine of the angle of injection as this is a likely dust source distribution from a rough surface. Figure 2 shows that deposition is confined to the inside of the torus. The units are arbitrary, as we have not specified the quantity of dust produced. Hopefully, more information on the quantity of dust produced per shot will become available in the near future.

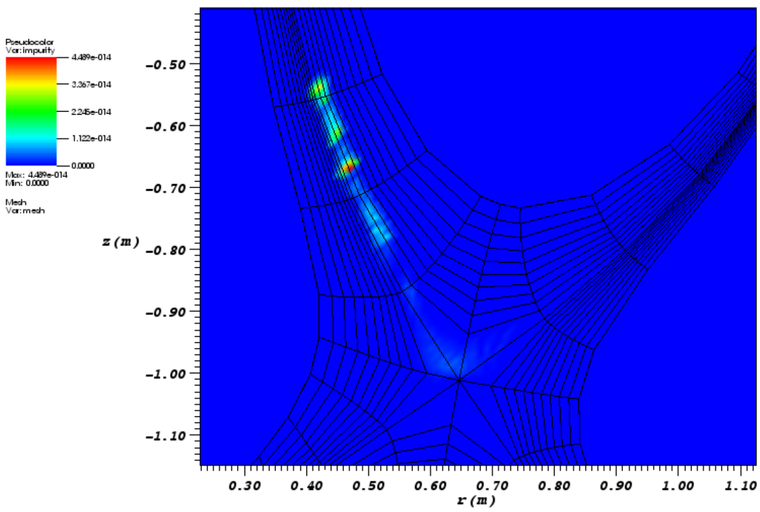

Figure 2: Impurity deposition for micron radius graphite grains in MAST.

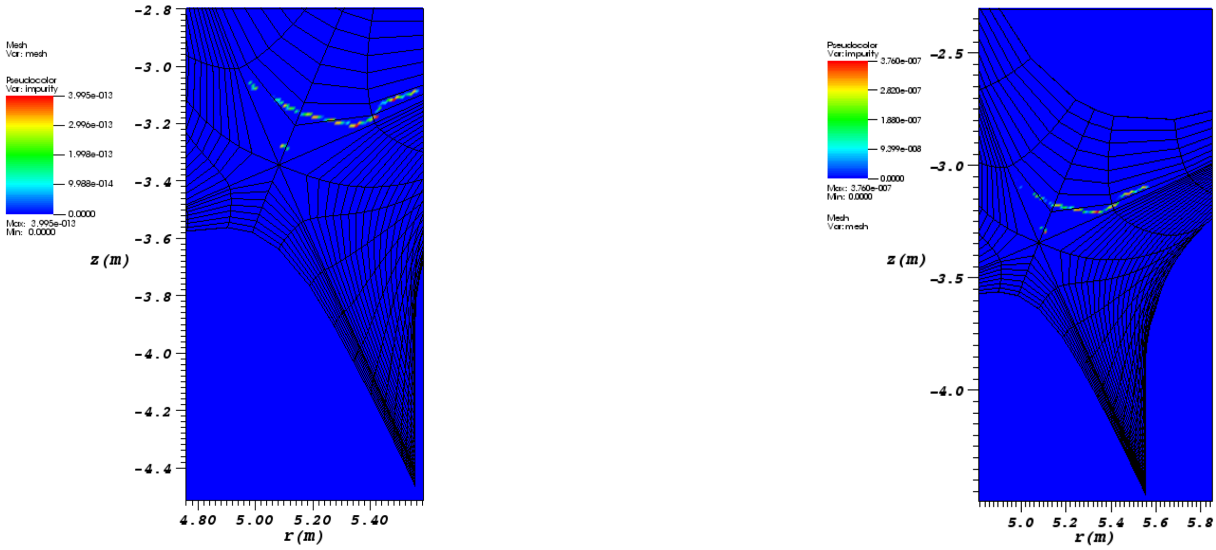

Figure 3: Impurity deposition for 1 micron (left) and 100 micron (right) radius tungsten grains in ITER.

For ITER, we repeat the analysis, and it turns out that micron radius carbon dust is confined to the plasma near the base of the divertor even at an initial speed of 10^3 ms^{-1}. We therefore concentrate on tungsten dust for this study, as we are assuming it stays intact in the liquid phase, and can therefore survive at higher temperatures. We find that 10^3 ms^{-1} is required for micron radius tungsten dust to reach inside the separatrix. As there is little knowledge about tungsten divertors, it is possible that the modal size of tungsten dust may be larger. If we increase the dust radius to 100 microns, we find that the initial speed required is only 10 ms^{-1} (see figure 3). This emphasizes that the characterisation of dust from tungsten divertors, and the expected mass of dust created per shot is of critical importance to ITER.

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