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Transport of Pre-Characterized Tungsten Dust in STOR-M

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ABSTRACT

- Tungsten microparticles injected into the STOR-M tokamak (R/a = 46 cm/12.5 cm, B_T = 0.7 T, I_p = 30 kA) are accelerated along the plasma flow direction and deviate from their free-fall trajectories.
- Ion-drag force derived from a modified Barnes' model agrees with the experimental data within experimental uncertainties when STOR-M plasma parameters and the mean W-dust size are applied.
- Post-mortem sampling reveals size reduction and compositional changes downstream, suggesting strong interactions between the plasma and dust.

EXPERIMENT

INFLUENCE OF PLASMA ON DUST

- Dust plume entering from the top falls into and diffuses within STOR-M.
- The amount of in-vessel dust is controlled by a pre-set **delay time (t_{delay})** between dust dispenser activation and the Ohmic Heating (OH) discharge in STOR-M [1].
- Horizontally and vertically viewing cameras record images of glowing dust particles in the plasma (1 μs exposure time, 2156 frames/s frame rate, 800 × 800 pixel frames, and 6.6 cm × 6.6 cm view field at focus planes). Examples of the reconstructed dust trajectories superimposed on the images are shown in ***FIG 1.*** *(time stamps: time after OH discharge)*

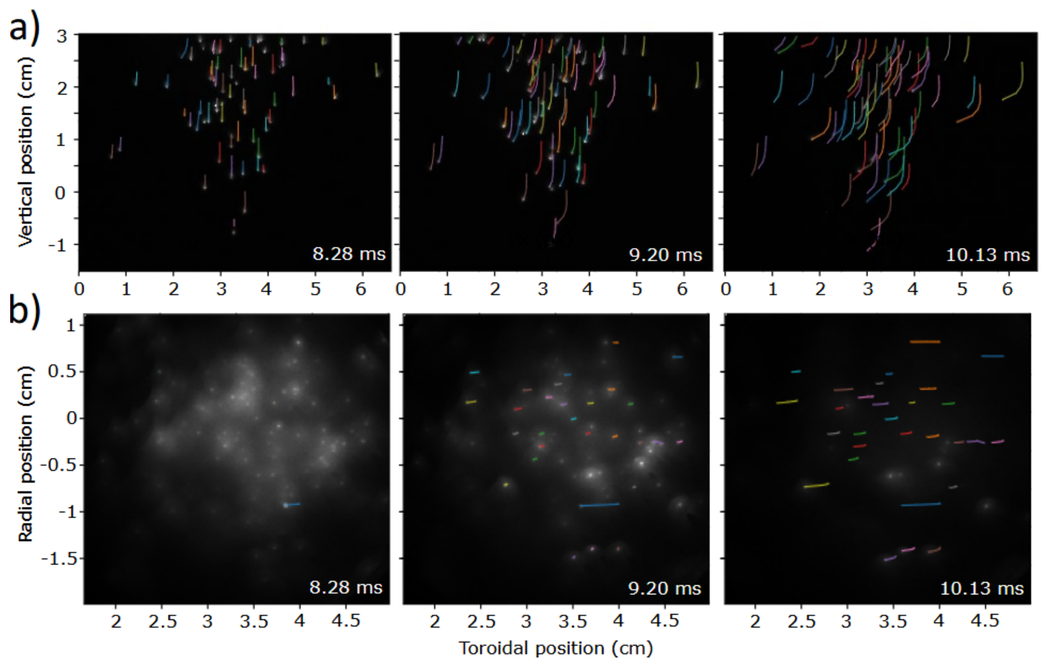

FIG 1*: Typical dust trajectories for a) side camera and b) bottom camera*

PLASMA PARAMETERS

- Ion Doppler Spectroscopy (IDS) measured toroidal drift velocities of C-VI impurity ions (~plasma vel.) utilizing the 529.05 nm emission line.
- Plasma parameters were recorded with and without tungsten dust injection over multiple discharges for different delay times.
- ***FIG 2*** shows evolution of plasma parameters, with t = 0 ms marking the start of OH discharge, for the cases with two delay times, and without dust injection. Solid lines represent mean values over at least three shots, while the shaded regions indicate standard deviations.
- The amount of dust increases with delay time within the chosen range, and the plasma quality generally degrades as the dust amount increases.

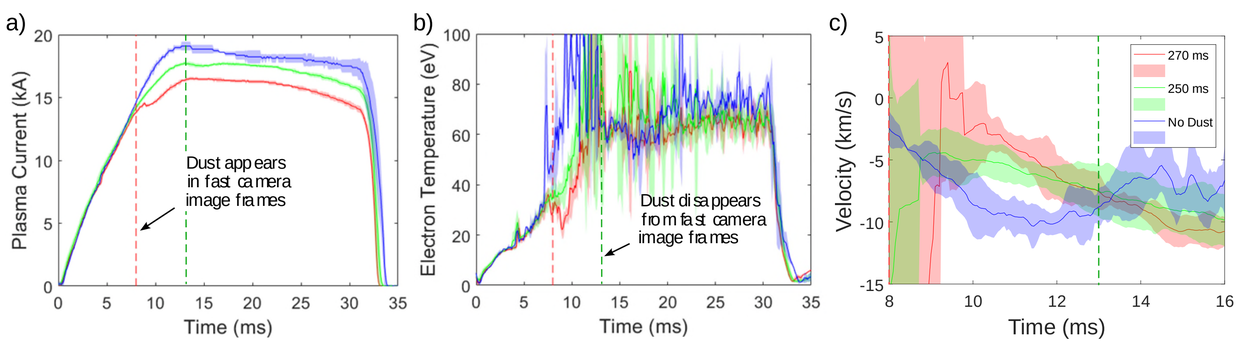

FIG 2*: a) plasma current, b) Spitzer temperature, and c) plasma flow velocity*

DATA ANALYSIS

DUST KINEMATICS

- Dust velocity (***FIG. 3a***) and acceleration (***FIG. 3b***) distributions: Based on time-derivatives of the smoothed (second-order Savitzky–Golay filter) trajectory (or velocity) of each particle over its life when visible.
- Mean velocity and acceleration are along the plasma flow direction.
- When the plasma flow direction is reversed by changing the plasma current direction in STOR-M, the dust drift direction reverses as well.

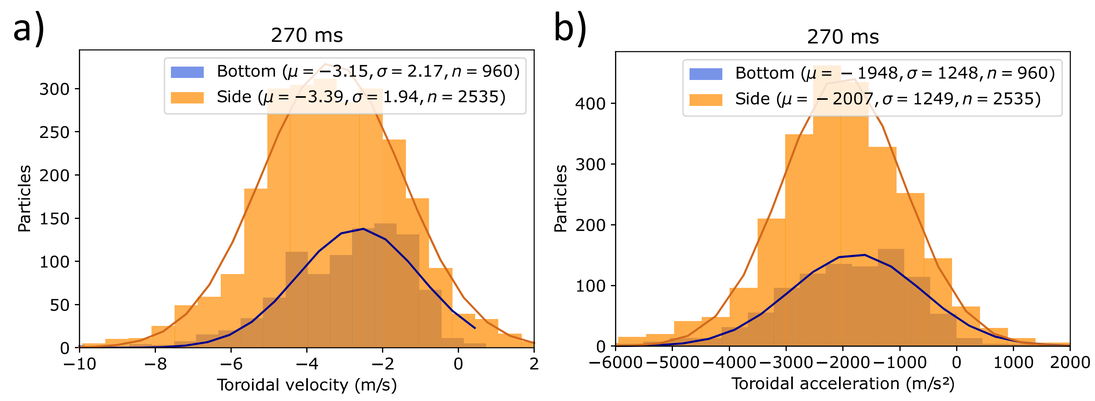

FIG 3: *Distribution of dust a) velocity and b) acceleration*

THEORETICAL MODELLING

- Ion-drag force based on Coulomb collisions between flowing ions in plasma and the charged dust (modified Barnes' Model [2]) is derived.
- Force based on STOR-M plasma parameters and the average W-dust radius (42 nN) agrees within experimental error (***FIG. 4***).

$$\mathbf{F}_{\mathrm{id}} = \frac{4\pi}{3} m_i n_i r_d^2 v_s \mathbf{u}_i \left(1 - \frac{2e\phi_d}{m_i v_s^2}\right) + \frac{8\pi}{3} \frac{n_i r_d^2 e^2 \phi_d^2}{m_i v_s^3} \mathbf{u}_i \ln\left(\frac{b_{90}^2 + (\lambda_D + r_d)^2}{b_{90}^2 + b_c^2}\right)$$

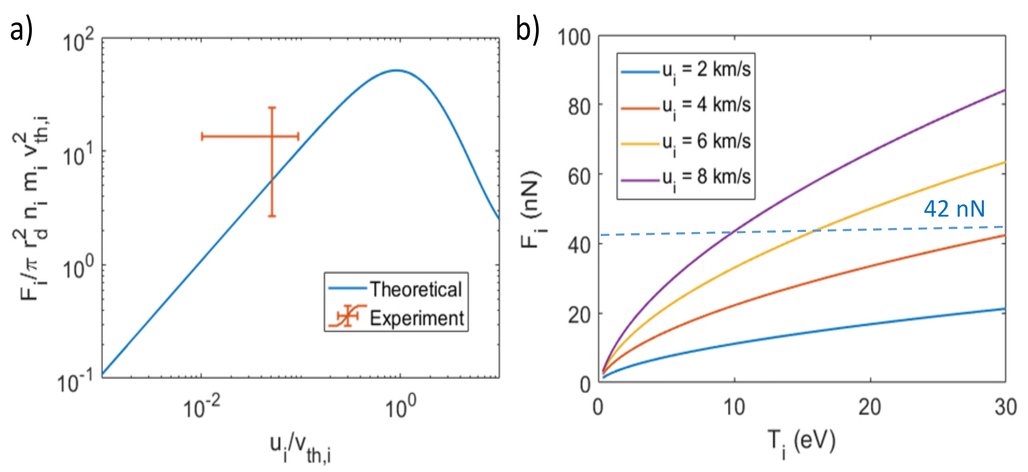

FIG 4*: Theoretical ion-drag force and the measured experimental data point*

POST-MORTEM SAMPLING

- Post-mortem dust sampling was collected from the STOR-M floor with carbon sticky tapes at varying toroidal locations.
- A significant reduction in particle size and increased compositional diversity downstream of plasma flow from the dispenser are observed.

CONCLUSION

- ❖ Ion-drag force is identified as the cause of the observed acceleration of dust particles along the toroidal plasma flow direction.
- ❖ The interpreted toroidal force exerted on dust particles agree with that derived based on a non-magnetized Barnes' model when the estimated STOR-M tokamak parameters and mean size of W-dust are applied
- ❖ Dust size distribution suggests selectively enhanced transport of smaller particles, ablation, and/or some contribution from native dust.

ACKNOWLEDGEMENT

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References: [1] NELSON, N. Tungsten dust injection into the STOR-M tokamak. Radiat Eff Defect S. 178.11-12 (2023) 1344–1349., [2] MELZER, A., Physics of dusty plasmas, Vol. 962, Springer, Cham, Switzerland (2019).