Friction coefficient dependence on electrostatic tribocharging

Supplementary information

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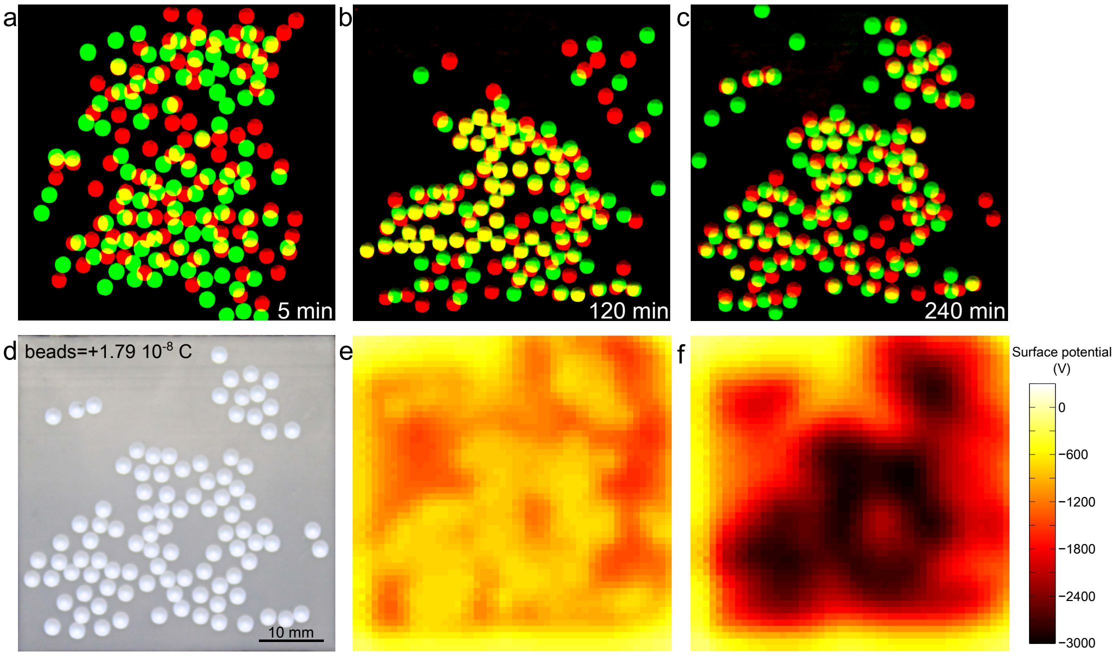
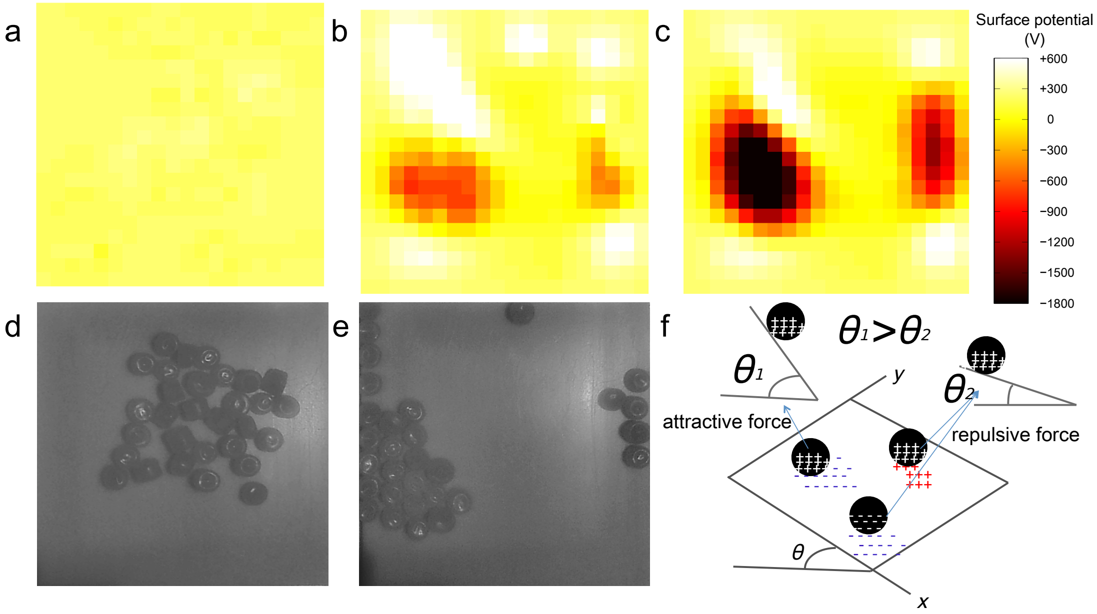
1. Rolling glass beads over PTFE and the tribocharging effect on static friction coefficient.



Supplementary Figure S1. Results from a replicate experiment following the description given in Fig. 2.



Supplementary Figure S2. Tribocharging effect on friction angles. Potential maps of: (**a**) PE pellets on clean PTFE prior to shaking, (**b**) pellets shaken for 3000 seconds on PTFE and (**c**) PTFE after removal of PE pellets. (**d**) and (**e**) are pictures of PTFE with PE pellets prior to and after shaking in the planetary table, respectively. Schematic description (**f**) of tribocharging PE pellets with PTFE. Attractive (repulsive) forces between PTFE and PE contribute to increase (lower) friction angle.

2. Calibration of lateral deflection: *The Wedge Method*.

Calibration of lateral deflection followed the so-called wedge calibration method, first proposed by Ogletree, Carpick and Salmeron[1] and after improved by Varenberg, Etsion and Halperin[2]. This method is appropriate for sharp AFM tips[3] and basically consists in scanning a surface with well-defined slopes under various load conditions. There are many others calibration methods[4,5,6] for lateral force microscopy but the wedge method is a friendly, widely accepted and highly cited calibration procedure[7].

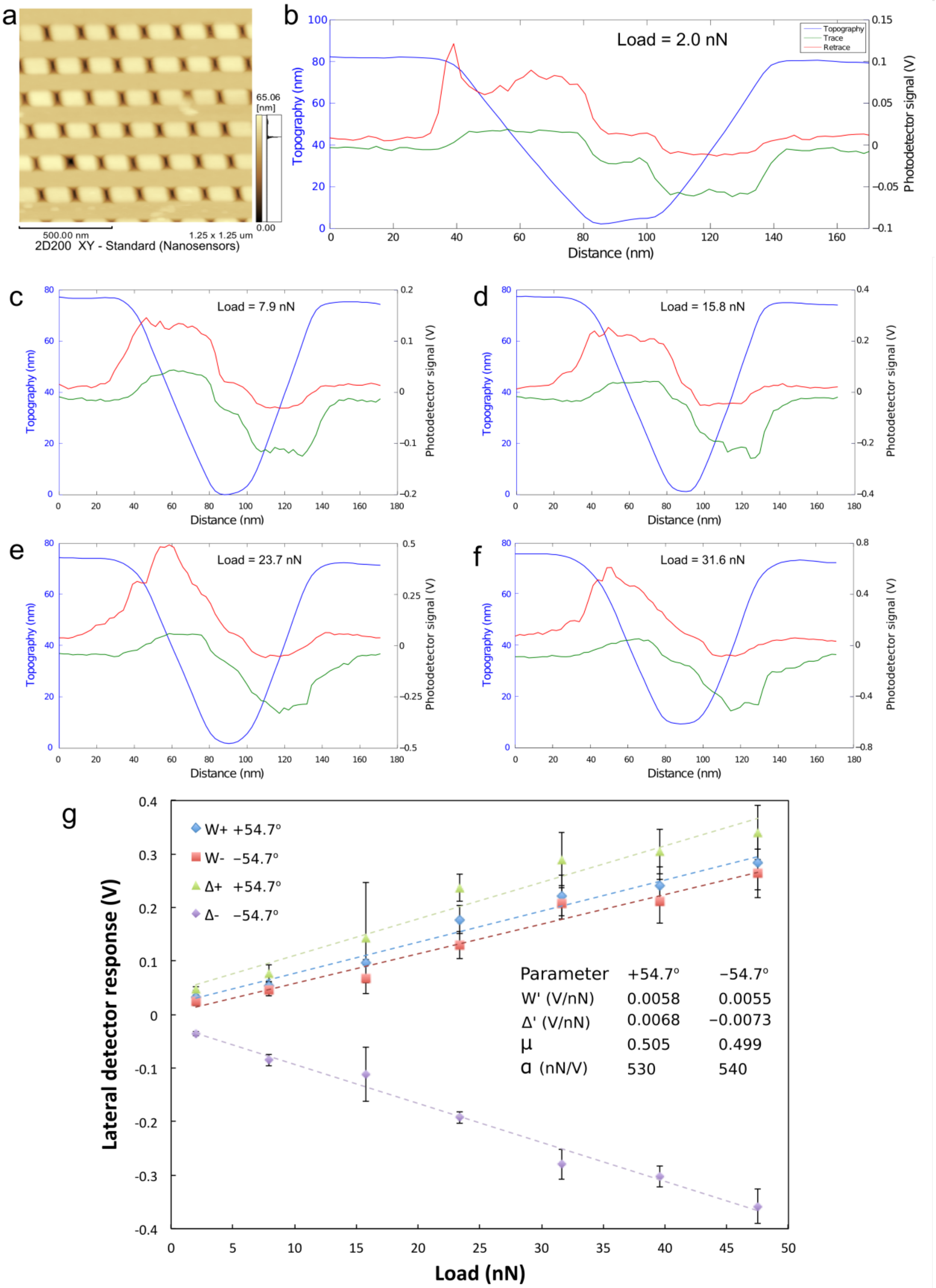
For the wedge method a 2D200 XY-Standard sample produced by Nanosensors (Neuchatel, Switzerland) was imaged in contact mode at a scan angle of 90 degrees under different loads L. The standard sample consists of a 2-dimendional lattice of inverted square pyramids with 200nm pitch, sidewall angles of $\theta=54.7^o$ and etched into a silicon chip. For the wedge calculations[1], two parameters are extracted from each line-scan, the half-width friction loop $W(L)$ and the offset friction loop $\Delta(L)$. Experimentally, the slopes $W'=dW/dL$ and $\Delta'=d\Delta/dL$ are used in calculations for the calibration factor α as follows:

$$\alpha\Delta' = \frac{(1+\mu^2) sin\theta\ cos\theta}{cos^2\theta - \mu^2 sin^2\theta} \tag{SE1}$$

$$\alpha W' = \frac{\mu}{cos^2\theta - \mu^2 sin^2\theta} \tag{SE2}$$

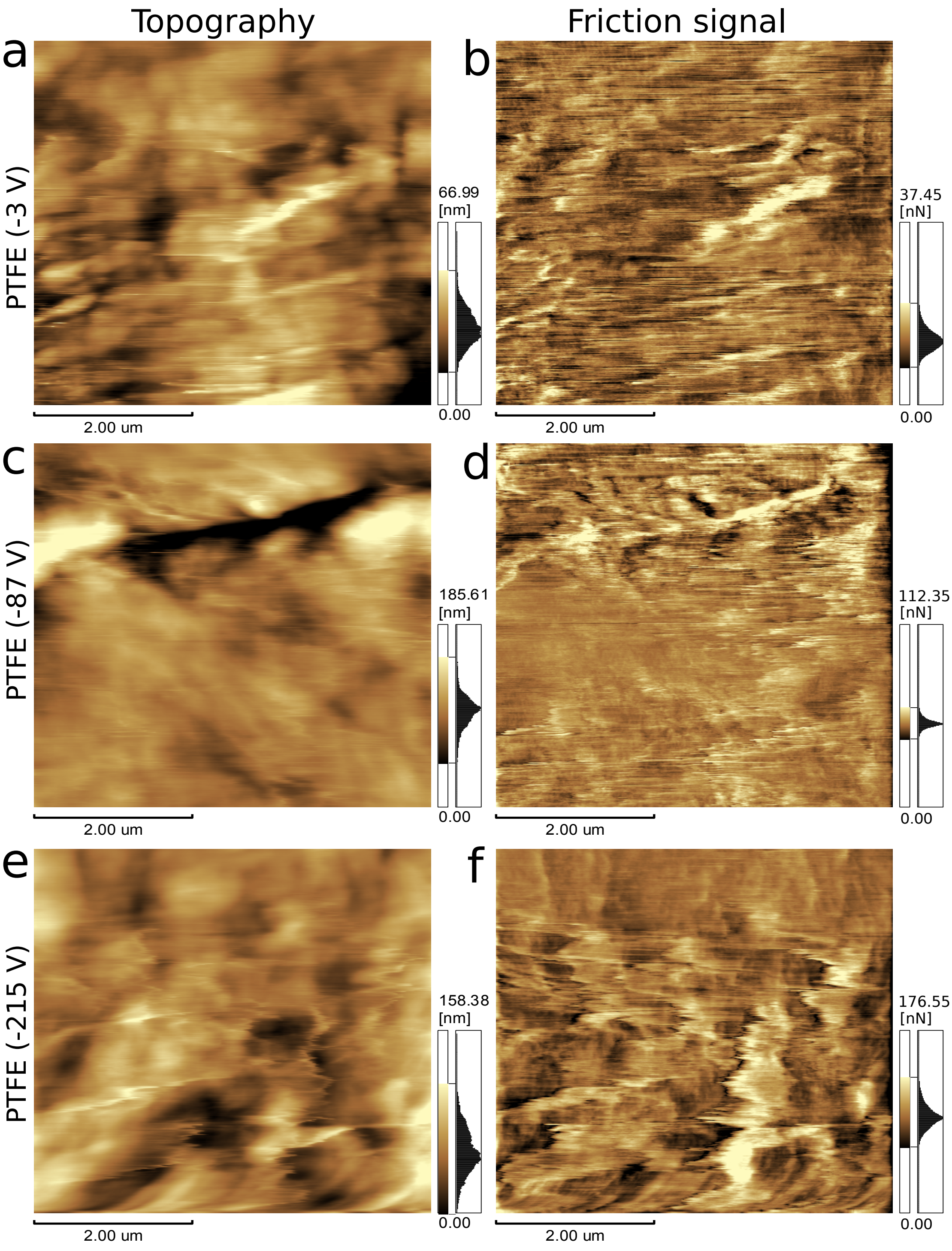
$$\mu + \frac{1}{\mu} = \frac{2\Delta'}{W' sin2\theta} \tag{SE3}$$

where μ is the friction coefficient and θ the sidewall angle. The equation SE3 is a quadratic equation and the real solution[2] must be positive and smaller than $1/tg\theta$. Figure S3 shows a summary of the wedge procedure/calculations for a gold/chromium backside coated silicon nitride probe (OMCL-TR800PSA-1) performed on a scanning probe microscope (SPM-9600, Shimadzu) under controlled temperature (25±1 °C) and relative humidity (50±1%). The calibration factor α necessary to convert the lateral signal (Volts) into units of force (Newtons) is 530 nN/V for the positive slope and 540 nN/V for the negative slope.

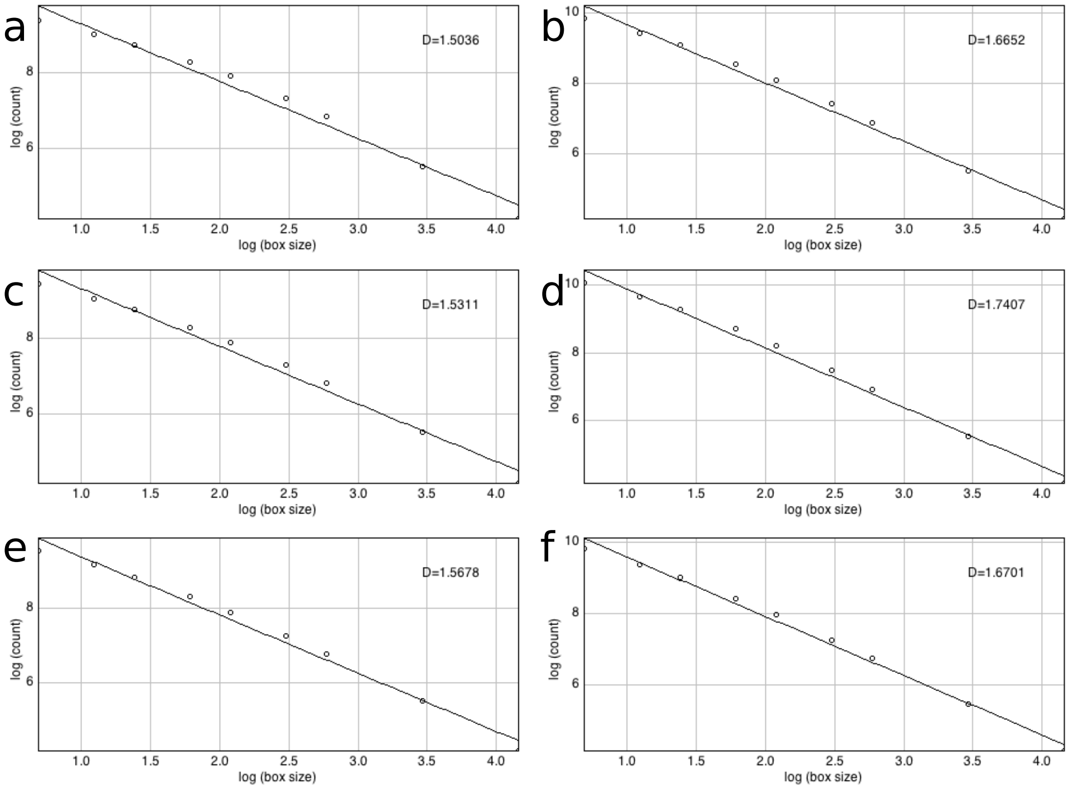


Supplementary Figure S3. The Wedge method calibration for lateral force microscopy. (**a**) Topography of 2D200 XY – Standard sample and (**b-f**) the lateral friction loop (and topography) as function of distance for one line-scan under different loads. The half-width friction loop *W* and the offset friction loop *Δ* as a function of applied normal load as well as the friction coefficients μ and the calibration factor α for each slope ($\theta=+54.7^o$ and $\theta=-54.7^o$) are given in (**g**). The error bars are based on the standard deviations of at least four line-scans.

3. Lateral Force Microscopy (LFM).

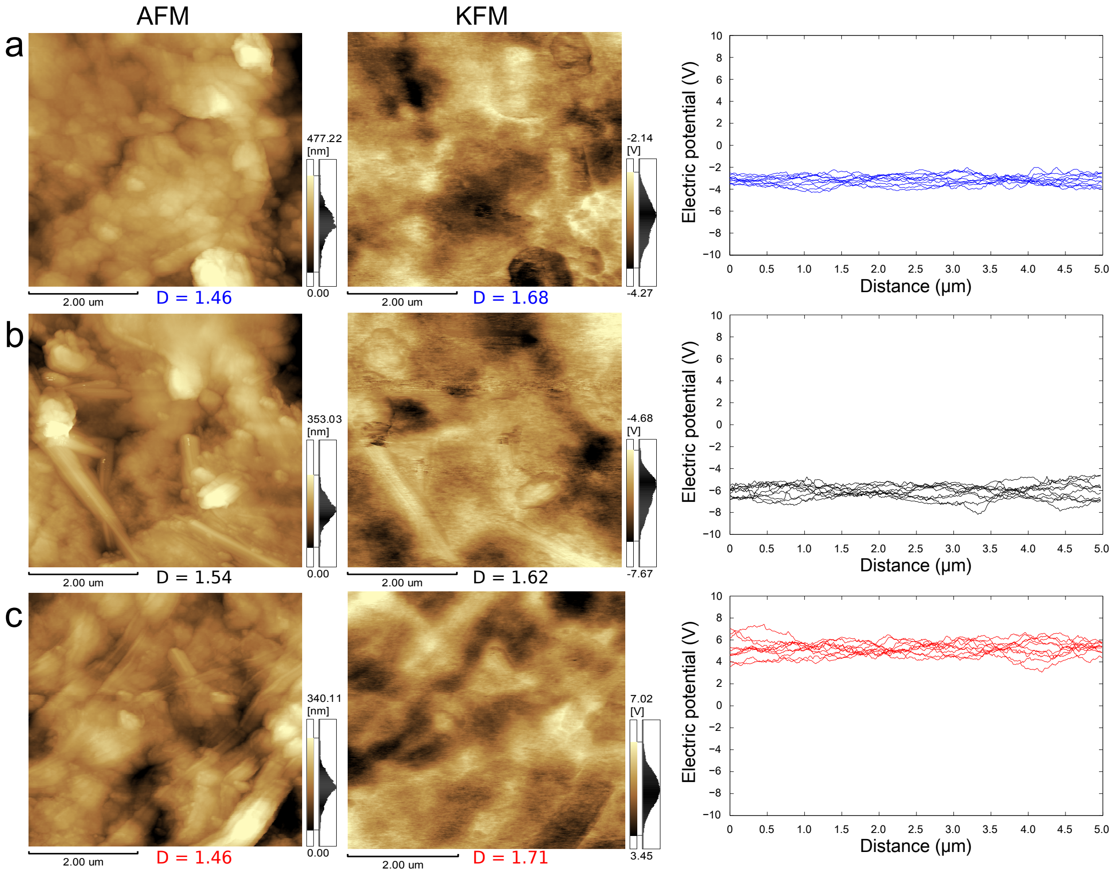


Supplementary Figure S4. Lateral Force Microscopy (LFM) of neutral and tribocharged PTFE sheets. Topography (left) and lateral force images (right) obtained by LFM on (**a-b**) discharged and (**c-d**), (**e-f**) tribocharged (measured with macroscopic Kelvin probe) PTFE samples.

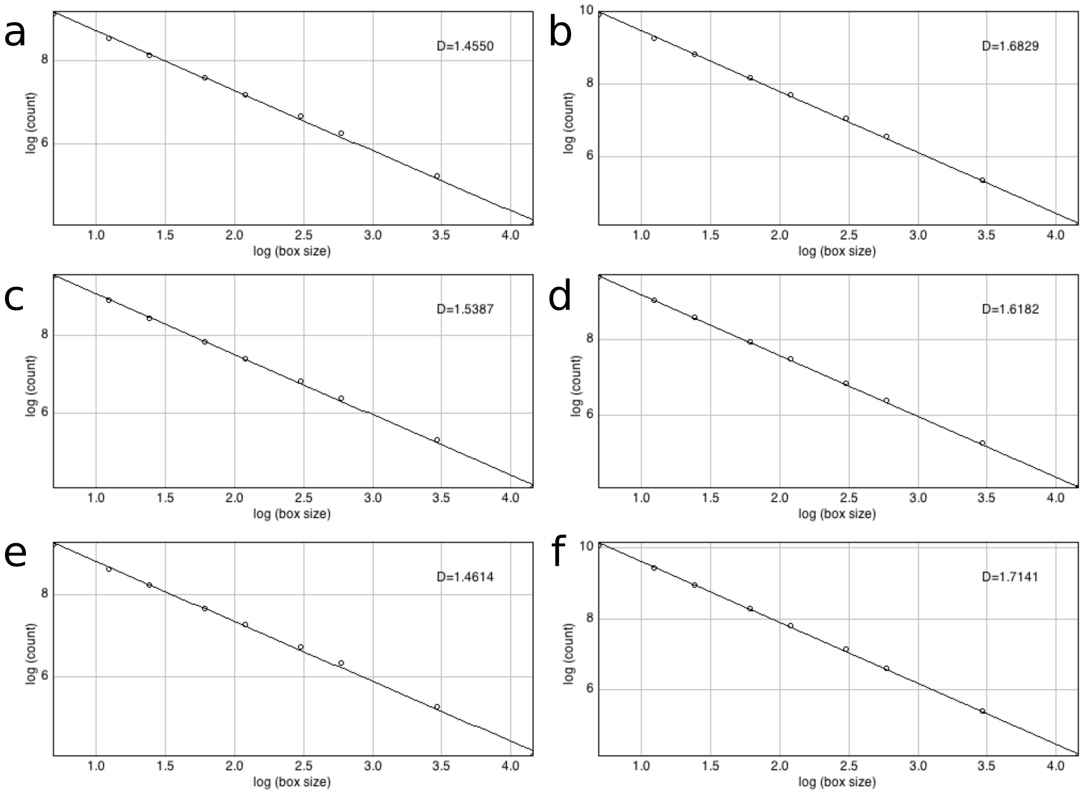


Supplementary Figure S5. Fractal dimension *D* of topography (left) and lateral signal (right) calculated from images shown in Figure 4 (*article*) using the box count method. Fractal dimension *D* of PTFE with (**a-b**) –3 V, (**c-d**) -87 V and (**e-f**) -215 V.

4. Kelvin Force Microscopy (KFM).



Supplementary Figure S6. Kelvin Force Microscopy (KFM) of neutral and lightly tribocharged PTFE sheets. Topography (left) and Kelvin force images (right) obtained by KFM on (**a**) discharged, (**b**) negative tribocharged and (**c**) positive tribocharged PTFE samples. Static potential profiles following ten different lines traced in KFM images are shown.



Supplementary Figure S7. Fractal dimension *D* of topography (left) and KFM (right) calculated from line profiles of Figure S7. Fractal dimension *D* of (**a-b**) PTFE neutral, (**c-d**) positive tribocharged and (**e-f**) negative tribocharged.

5. Rolling experiments under bias

A PP film coated with aluminum on one side was biased using a 2410 high-voltage power supply (Keithley Instruments) and CoRR measurements were made on glass spheres (ϕ = 2,5 mm) rolling on the PP surface, following the procedure described in the experimental section. CoRR was unaltered by biasing the aluminum film up to 1 kV. After completing the experiments, PP films were scanned with a Kelvin electrode and the measured potentials were equal to zero, within experimental error.

6. Electrification with the liquid-contact method: The Chudleigh Method[8]

A PP film coated on one side with aluminum was charged using Chudleigh's method, by wetting its surface with cotton soaked on ethanol biased to the desired voltage, while the aluminum coated surface was grounded. The PP area was 8 x 12 cm^2 divided into 5 x 5 mm^2 spots that were contacted by the biased wet cotton for 5 seconds each, while this was displaced by a mechanical arm. After the completion of the scan, the electrode was removed while still biased. Then, the region was scanned with a Kelvin electrode kept at 2 mm above the surface and connected to a voltmeter (347, Trek), for surface potential mapping. PP charging was uniform, within ± 1V.

The results obtained for CoRR with the homogeneously charged film are shown in the Supplementary Table S1.

Supplementary Table S1. CoRR's value of a PP film coated with aluminum in one side charged with Chudleigh method[8].

Potential (V)	CoRR
-1000	0,016 ± 0,003
-100	0,013 ± 0,002
0	0,017 ± 0,002
100	0,015 ± 0,003
1000	0,012 ± 0,001

Thus, films evenly charged by Chudleigh method did not show significant CoRR changes. However, when the surface was not homogeneously electrified, rather complex behavior was observed which will be reported separately.

7. References

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