Supplementary Information for 'Measured long-range repulsive Casimir-Lifshitz forces'

Electrostatic Force Microscopy

Electrostatic Force Microscopy (EFM) is performed on the samples to ensure that any variation in surface charge is small and will not mask the Casimir-Lifshitz force[1]. The technique uses the same Atomic Force Microscope (AFM) but with a standard conductive cantilever (Budget Sensors) during a two-step process. The first scan is performed in tapping mode near the surface to determine the topography. Next, the piezo increases the tip-surface separation to 40 nm, and the surface is rescanned. During this second scan, a voltage is applied to the tip of the cantilever, and a feedback loop is used to keep the tip-surface separation constant using the topography information from the first scan. The phase difference between the cantilever's motion and the drive signal is proportional to the gradient of the force and can be used to determine electrostatic interactions[2,3]. For surfaces without significant charge, as the tip voltage is increased from 0 to 2 V, the phase difference signal will remain unchanged (Fig. S1). For dielectric samples with significant charge, the phase difference signal will show contrast corresponding to regions with varying amounts of charge (inset Fig. S1a). For both the silica and gold plates used in the experiments, no evidence of excess charge accumulation is found.

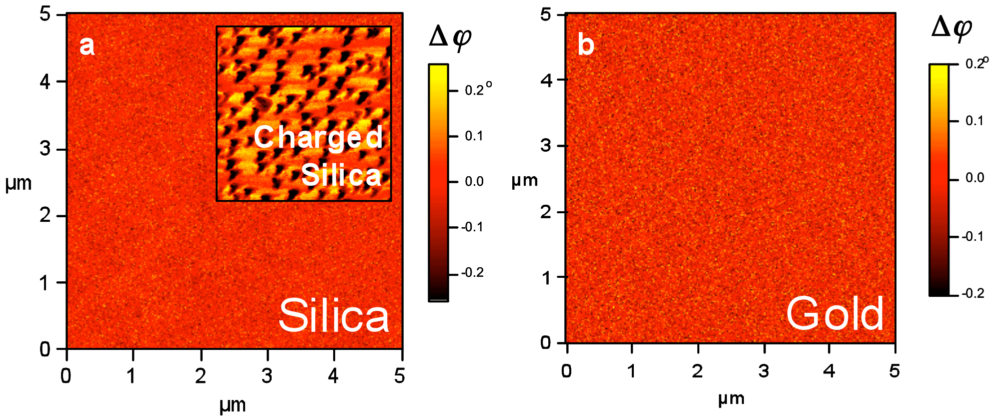

Fig. S1. With a standard conductive cantilever, electrostatic force microscopy is performed to ensure that the surfaces of both the silica (**a**) and gold (**b**) contain little charge variation after the cleaning procedure as determined by the spatial variation in the cantilever phase signal $\Delta\varphi$ with an applied voltage of 2 V at a distance 40 nm above the surface. An uncleaned silica sample exposed to electron irradiation from a scanning electron microscope shows clear contrast in the phase signal corresponding to patches of charge (inset **a**) for the same applied voltage.

Theory and calculations

Tabulated values for the optical properties of the materials are used for calculations. Data for gold and silica are from Ref[4]. Below ω = 0.125 eV, data is not available for gold, so the Drude model is used:

$$\varepsilon(\omega) = 1 - \frac{\omega_p^{\,2}}{\omega(\omega + i\gamma)},$$

where ω_p=7.50 eV and γ=0.061 eV.[5] The dielectric functions are then evaluated at imaginary frequencies[6] $i\xi = i\frac{2\pi k_B T}{\hbar} m$, where m is a positive integer or zero, according to:

$$\varepsilon_i(i\xi) = 1 + \frac{\pi}{2}\int_{x=0}^{\infty} \frac{x\,\mathrm{Im}[\varepsilon_i(x)]}{x^2 + \xi^2} dx.$$

$\varepsilon(i\xi)$ corresponds to the continuation of $\varepsilon(\omega)$ in the complex plane and physically represents the material's response to exponentially increasing fields rather than oscillatory ones[7]. For bromobenzene, less data is available, and a two-oscillator model is used[8,9]:

$$\varepsilon(i\xi) = 1 + \frac{C_{IR}}{1 + \left(\xi/\omega_{IR}\right)^2} + \frac{C_{UV}}{1 + \left(\xi/\omega_{UV}\right)^2},$$

where $\omega_{IR} = 5.47 \times 10^{14}$ rad/s and $\omega_{UV} = 1.286 \times 10^{16}$ rad/s are the characteristic absorption angular frequencies in the infrared and ultraviolet range, respectively, and C_{IR}=2.967 and C_{UV} =1.335 are the corresponding absorption strengths as reported in Ref[10]. The force is calculated using Lifshitz's equation with the above mentioned optical properties, with surface roughness corrections[11], as described in Ref[12]. The surface roughness is determined on the sphere and both plates using an optical profiler.

Figure S2 shows the distribution of height variations from an ideally smooth surface, which is used in the calculation of the roughness correction.

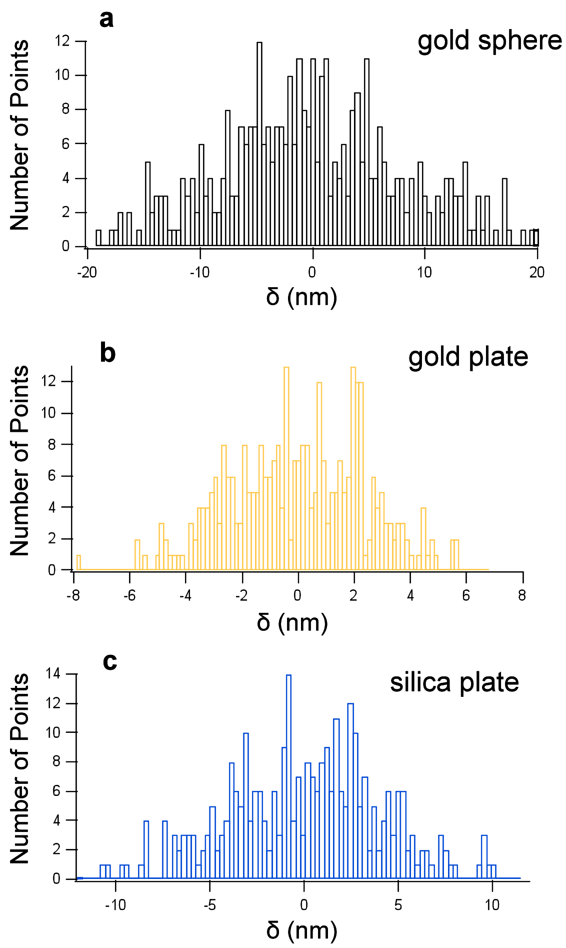

Fig. S2. Surface roughness measurements on the gold coated sphere (**a**), the gold coated plate (**b**), and the silica plate (**c**), as determined using an optical profiler. The bar heights represent the number of pixels with a displacement δ from an ideally smooth surface.

Distribution of force data

Force data was collected from 50 runs for both sets of data (gold and silica plates). Histograms of the force data at different distances show an approximately Gaussian distribution and no evidence of systematic errors (Fig. S3).

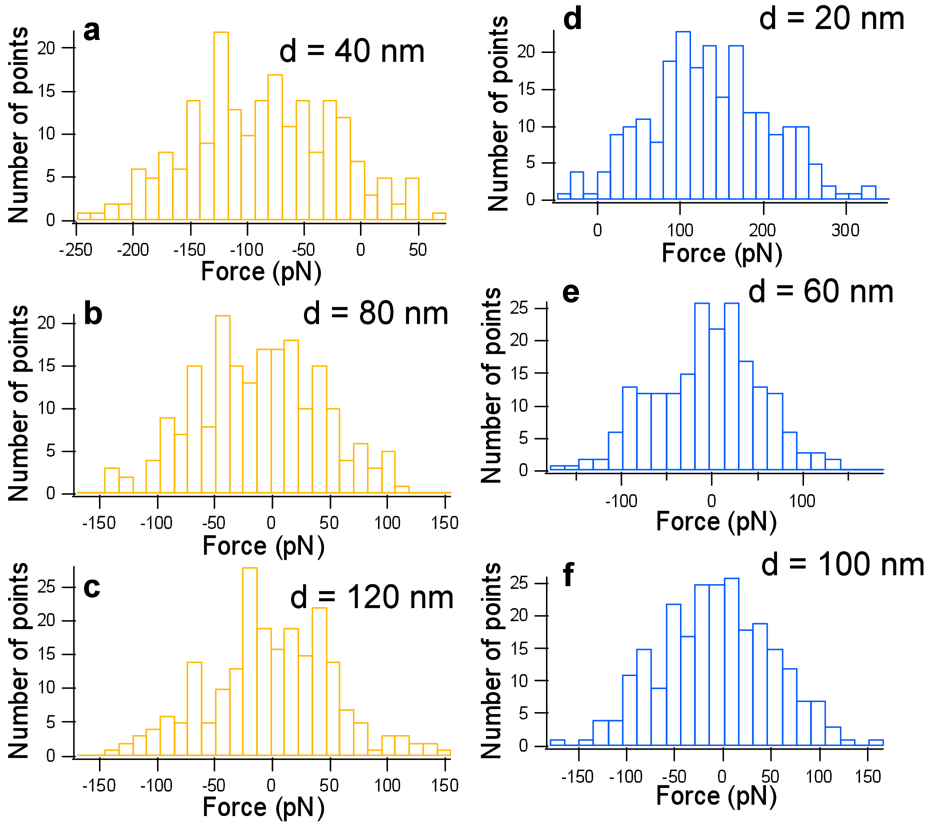

Fig. S3. Histograms of the force data show an approximately Gaussian distribution. Force data is collected from 50 runs, and distances are rounded to the nearest nm. Distributions are shown for the case of the gold sphere and gold plate (**a**,**b**,**c**) at three different sphere-plate separations. Similar data is shown for the case of the gold sphere and the silica plate (**d**,**e**,**f**).

1 Any charge that accumulates on a dielectric will be non-uniform, as it cannot easily move, and will be detectable through EFM as a charge variation across the surface.

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