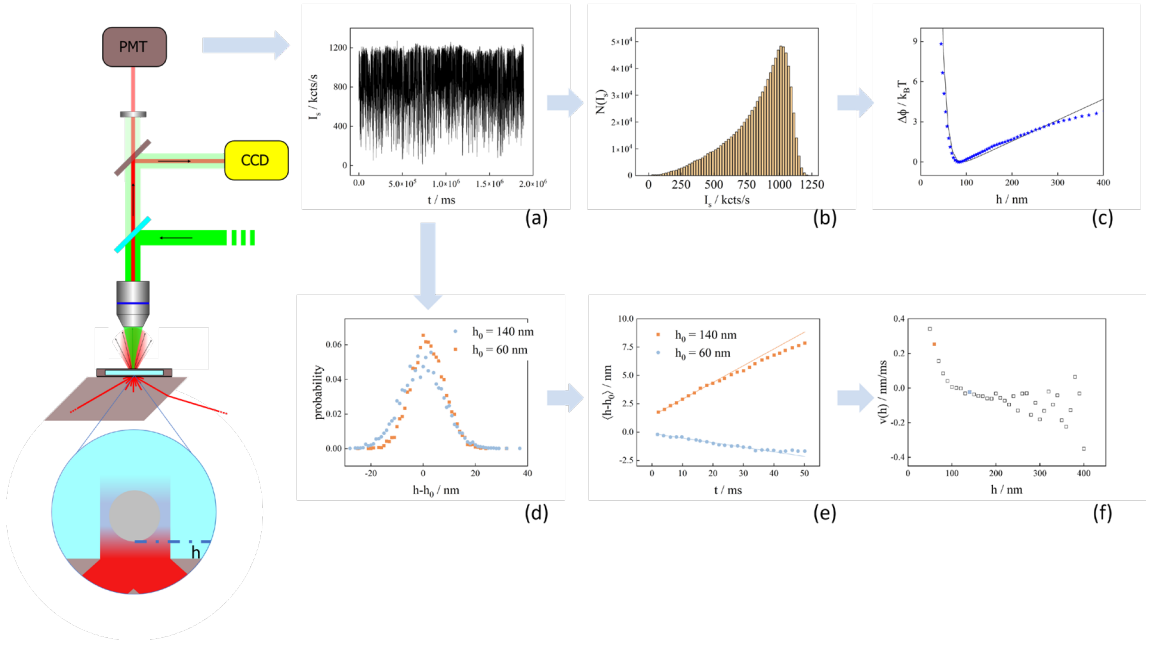


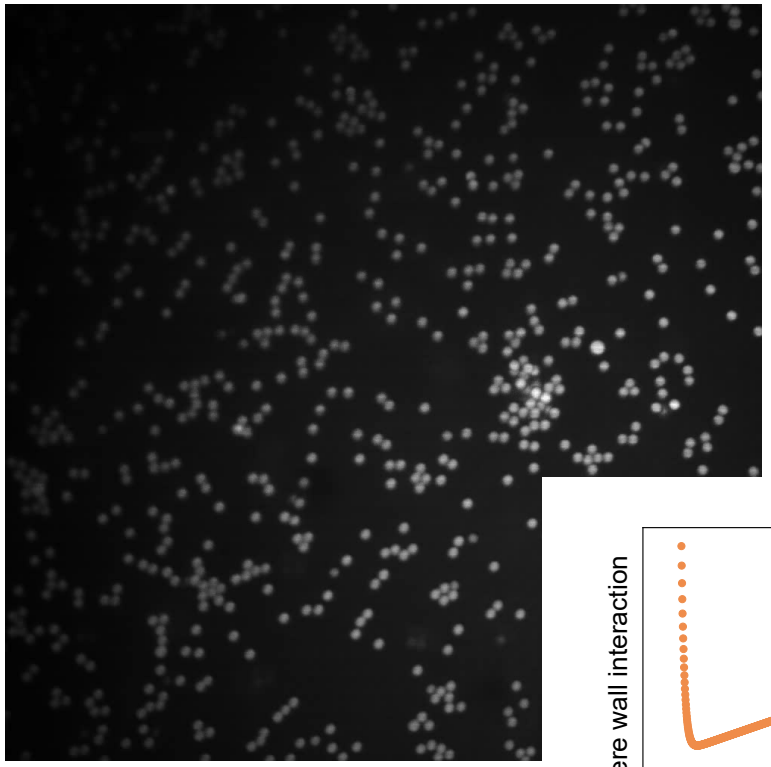
Analysing the Effect of Noise on Static and Dynamic Results from Total Internal Reflection Microscopy (TIRM)

30 September 2025 I J. A. Rivera- Morán and P. R. Lang

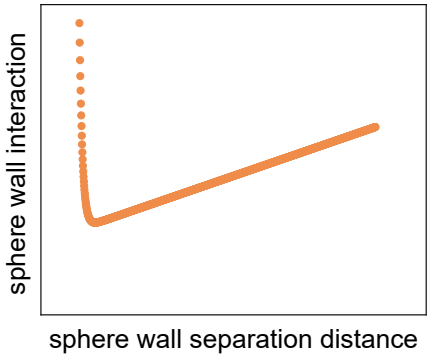
J.A. Rivera-Morán and P.R. Lang, Polymers, 15, 4208 (2023).
DOI:10.3390/polym15214208

INTERFACE EFFECTS IN COLLOIDAL SYSTEMS

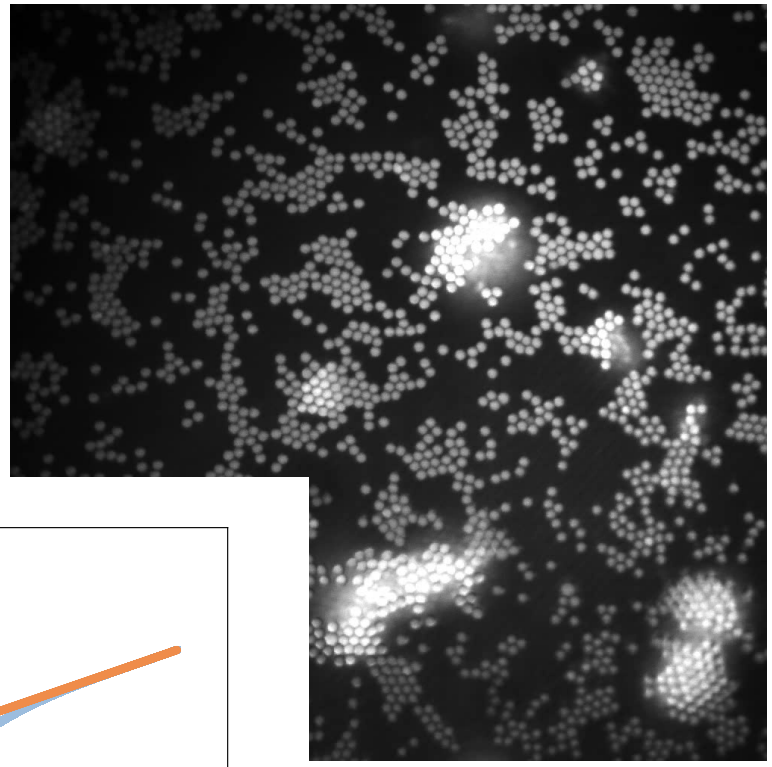
PS spheres
R = 1000 nm

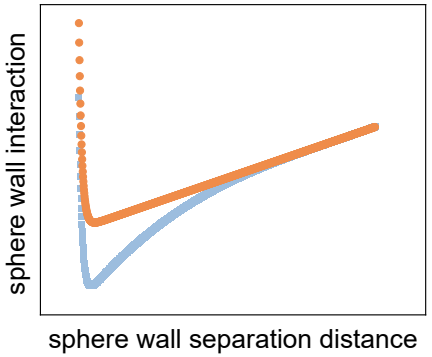


attractive potential

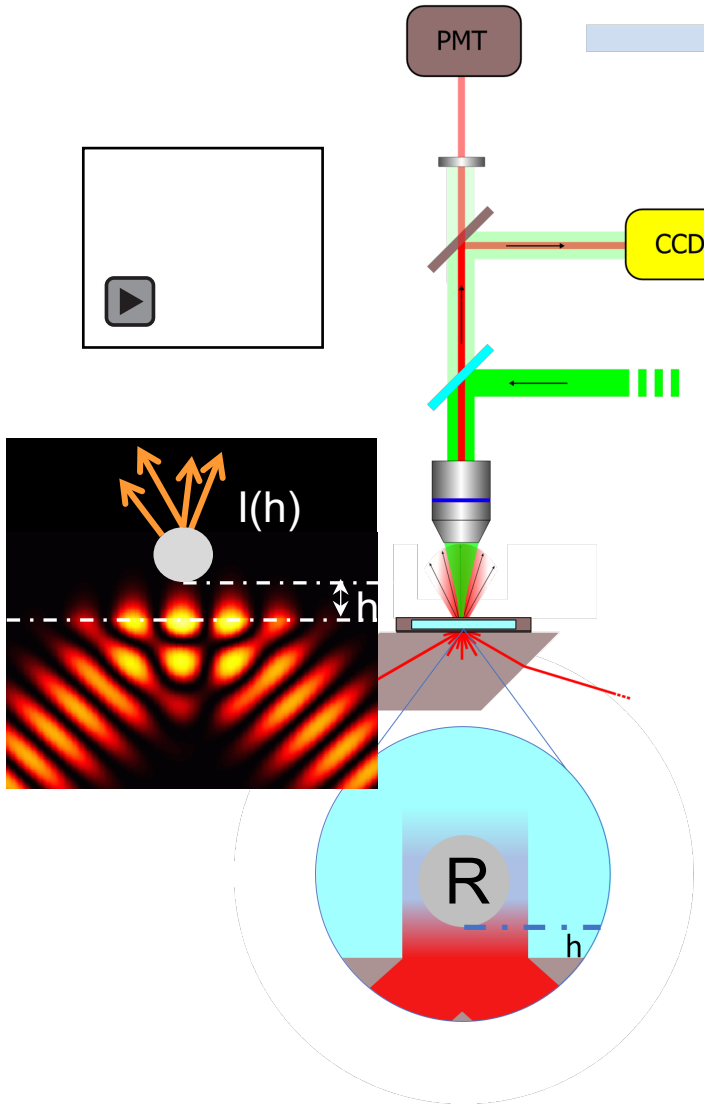


PS spheres
R = 1000 nm
plus rods L = 880 nm

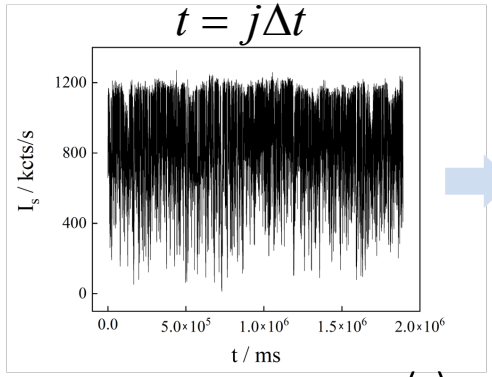




FUNCTIONAL PRINCIPLE OF TIRM

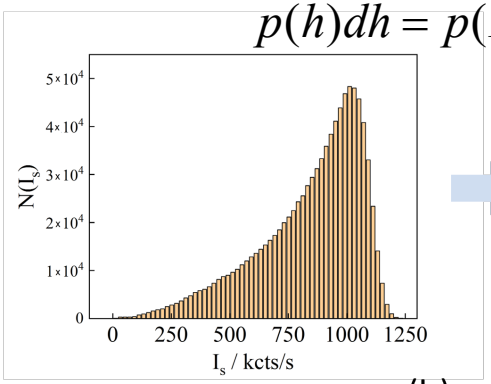


$t = j\Delta t$

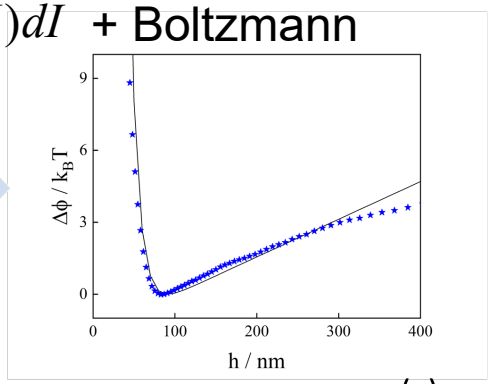


(a)

$p(h)dh = p(I)dI$ + Boltzmann

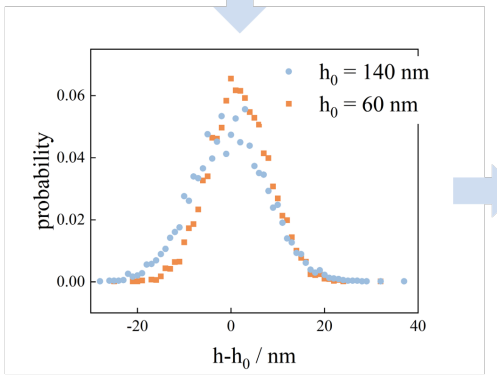


(b)

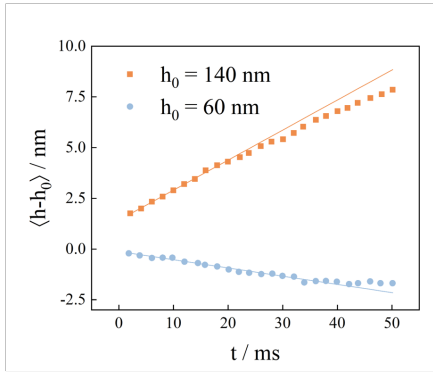


(c)

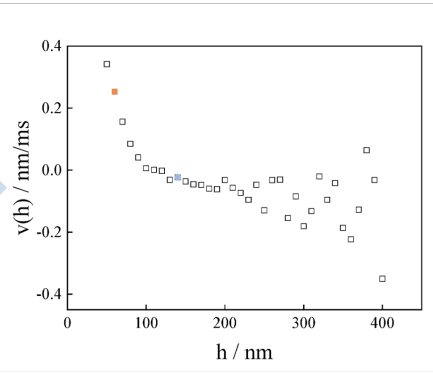
$$I(h) = I(h=0)\exp(-\Lambda h)$$



(d)



(e)



(f)

PERSISTENT ERRORS IN TIRM RESULTS

PS spheres
R = 3000 nm in 10^{-3} m NaCl

Simplest potential:
Superposition of electrostatic repulsion and gravity

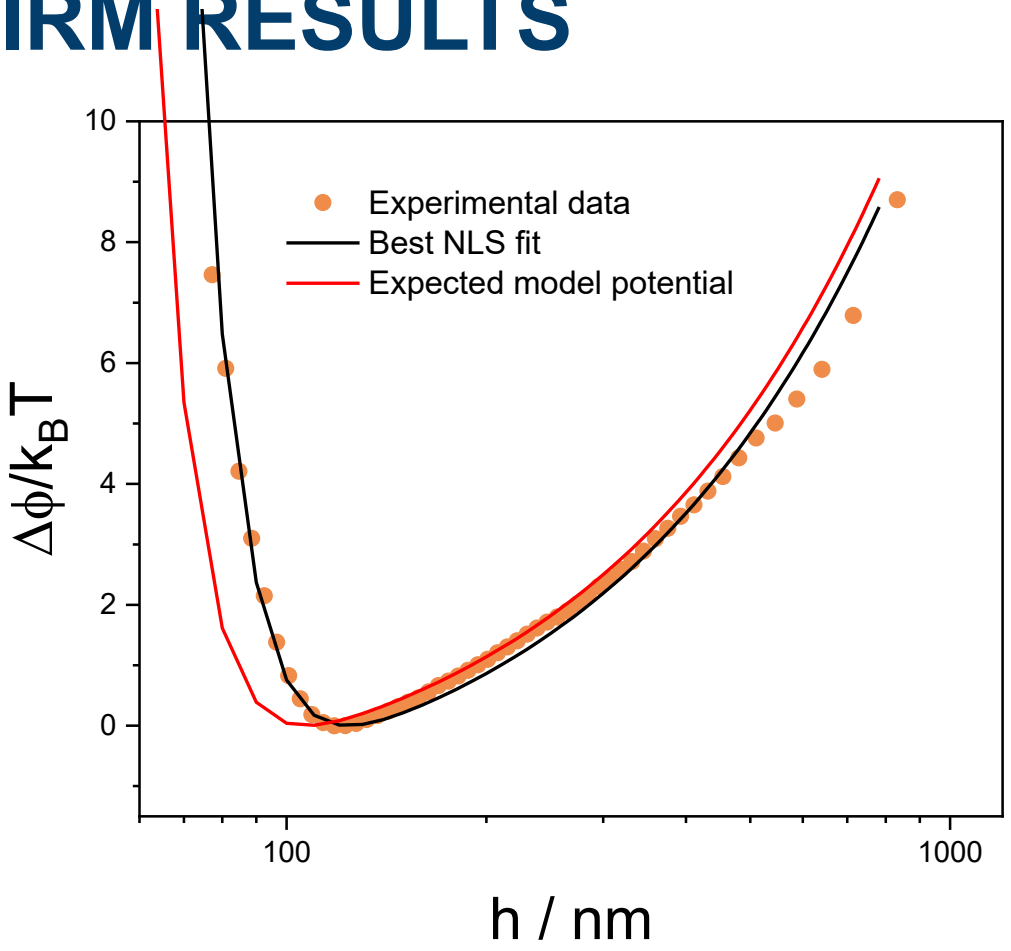
$$\phi(h) = B_{er} \exp\{-\kappa_D h\} + F_g h$$

F_g : buoyancy corrected weight force
κ_D^{-1}: Debye screening length

with $$h_m = \kappa_D^{-1} \ln\left(\frac{\kappa_D B_{er}}{F_g}\right)$$

$$\Delta\phi(h) = F_g\left[\kappa_D^{-1}\left(\exp\{-\kappa\Delta h\} - 1\right) + \Delta h\right]$$

$$\Delta = h - h_{\min}$$



	expect.	fitted
κ_D^{-1} / nm	9.6	11.4
F_g / fN	55	54

MD-SIMULATIONS TO ANALYSE SOURCES OF ERROR

1-D Langevin equation for particles close to an interface

$$\frac{\partial z}{dt} = -\xi_{\perp}^{-1}(z)\frac{\partial \phi(z)}{\partial z}\frac{\partial D_{\perp}(z)}{\partial z} + f(t) \qquad \text{with} \quad z = h + R$$

$f(t)$: fluctuating term due to thermal energy

Discretisation

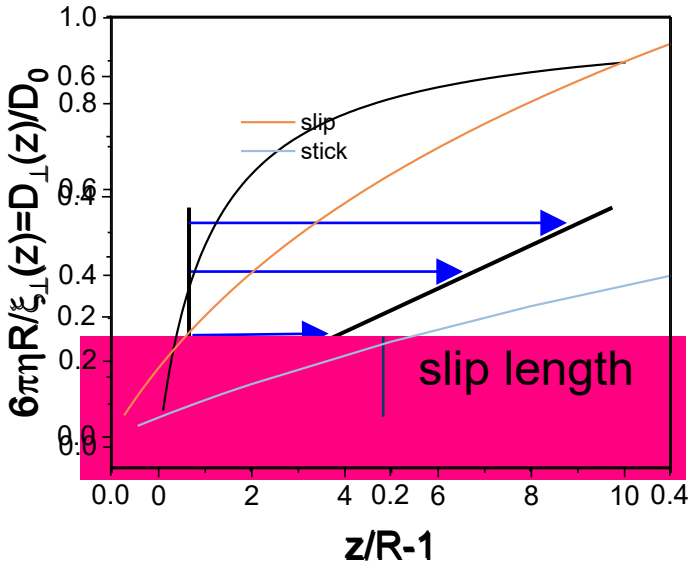
$$\Delta z = -\xi_{\perp}^{-1}(z)\frac{\partial \phi(z)}{\partial z}\Delta t + \frac{\partial D_{\perp}(z)}{\partial z}\Delta t + \Theta\sqrt{2D_{\perp}(z)\Delta t}$$

Θ: random number from Gaussian distribution

D. L. Ermak et al J. Comput. Phys. 35, 169–182 (1980).
D. S. Sholl et al J. Chem. Phys. 113, 9268–9278 (2000).

For stick boundary conditions

$$\xi_{\perp}^{-1} 6\pi\eta R \approx \frac{6h^2 + 2Rh}{6h^2 + 9Rh + 2R^2} = \frac{6z^2 - 10Rz + 4R^2}{6z^2 - 3Rz - R^2}$$



For partial slip:

$$\xi(h) \approx \frac{A}{h} + B\ln h + C - Dh\ln h$$

D. J. Jeffrey et al J. Fluid Mech., 139, 261-290 (1984).

Parameters for discrete slip lengths available from hydrodynamic simulations

M. Ekiel-Jezewska et al *Physicochem. Probl. Miner. Process., 54(1), 203-209 (2018).*

SIMULATION RESULTS: STATIC PROPERTIES

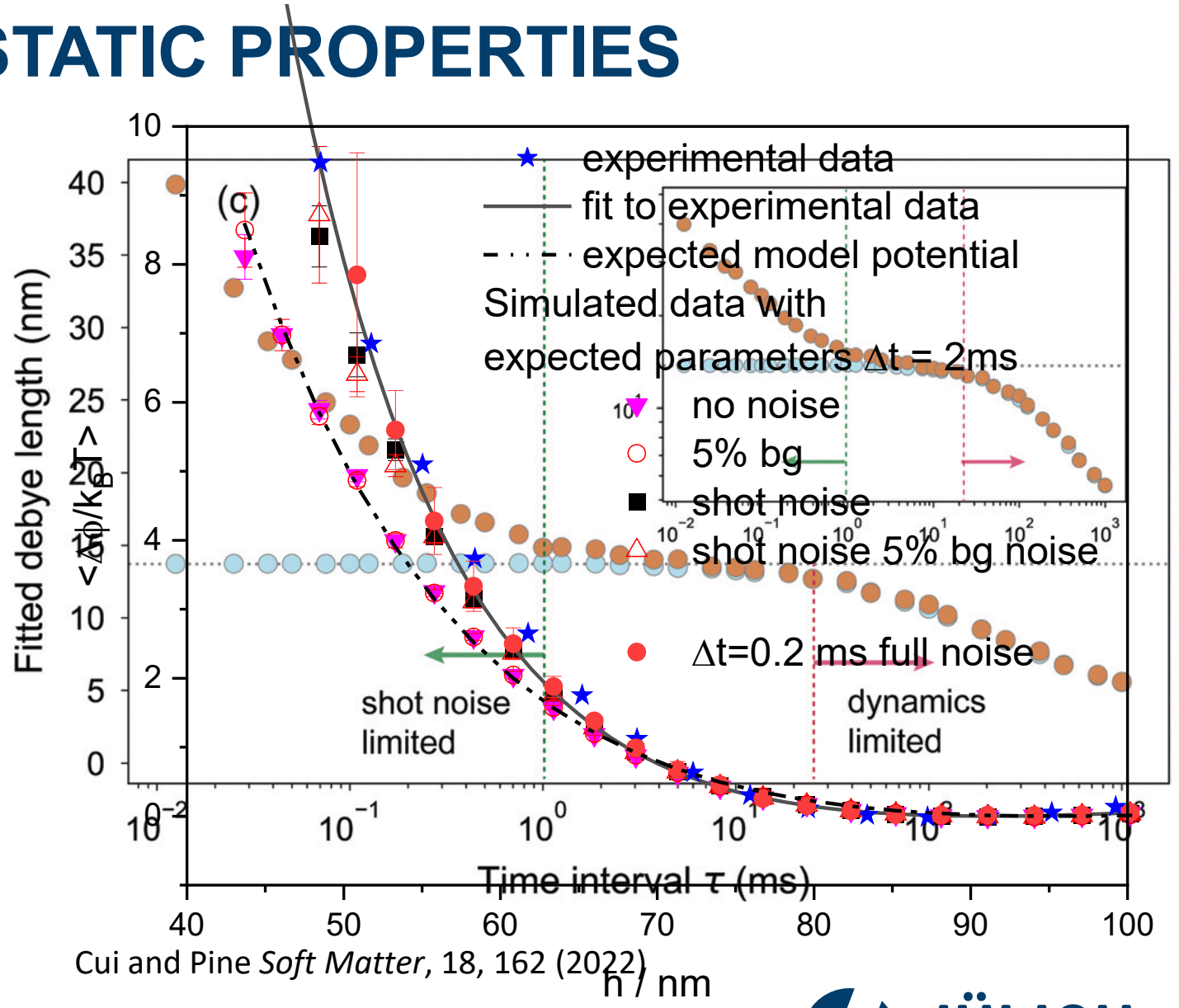
Main sources of potential errors:

- background scattering
  - typically <2%
- detector shot noise $P_{\Delta t}(n,\bar{n}) = \frac{\bar{n}^n}{n!}\exp\{-\bar{n}\}$

  Most significant at small CR

Catch 22
Long sampling times

- reduce shot noise effects
- increase motion effects



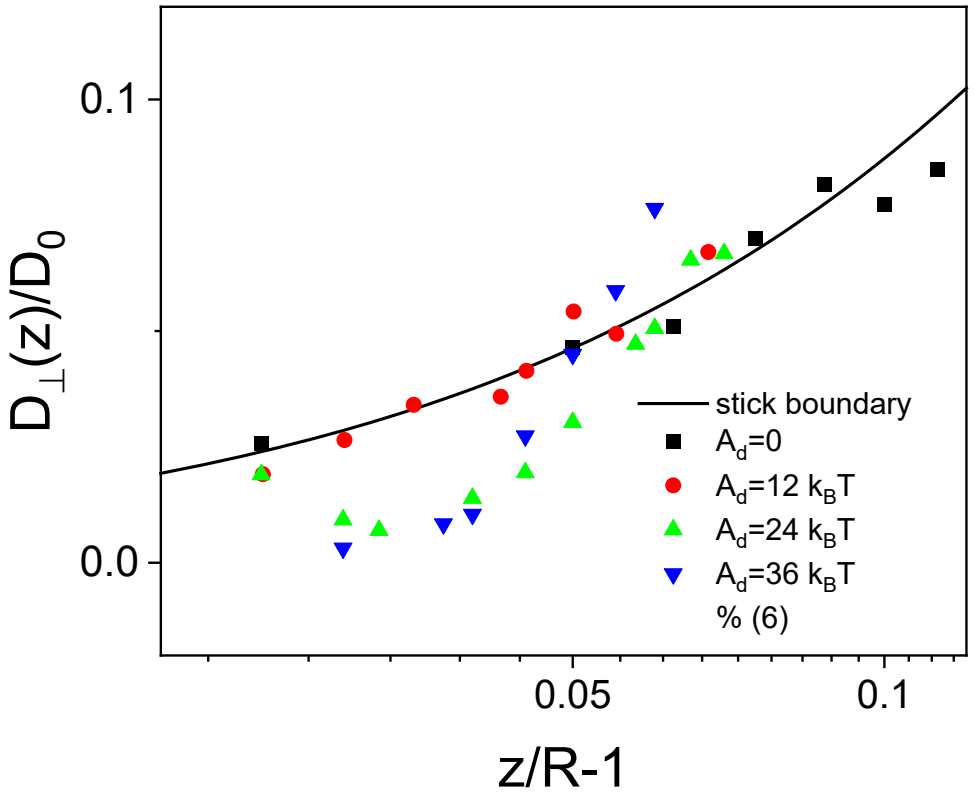
Cui and Pine *Soft Matter*, 18, 162 (2022)

SIMULATION RESULTS: DYNAMIC PROPERTIES

Experimental data
PhD Thesis Silvia de Sio 2018

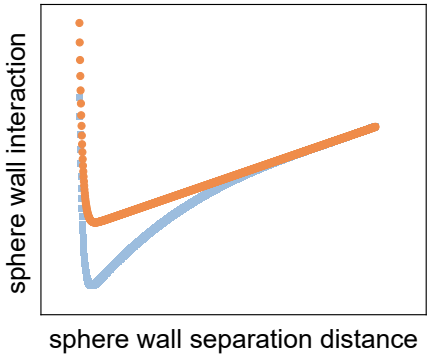
PS sphere
R = 2000 nm
plus rods L = 880 nm

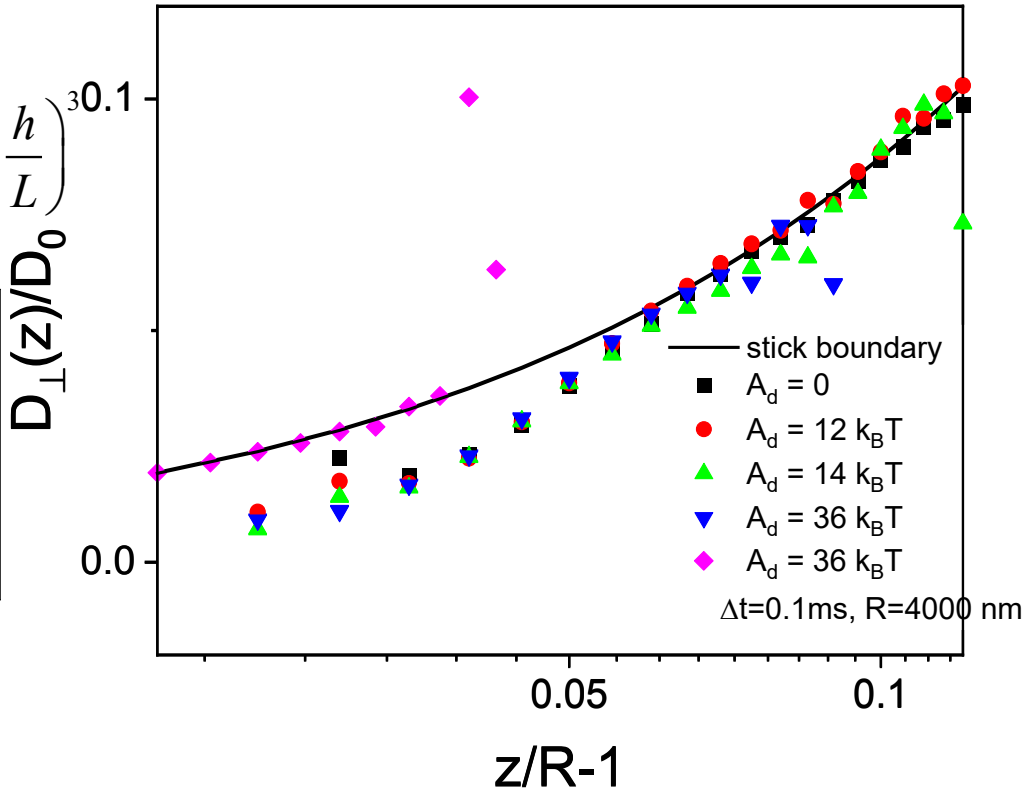
simulated data
Δt = 2 ms, 5%bg plus shot noise



$$\phi(h) = \phi_{er} + \phi_g + \phi_d$$

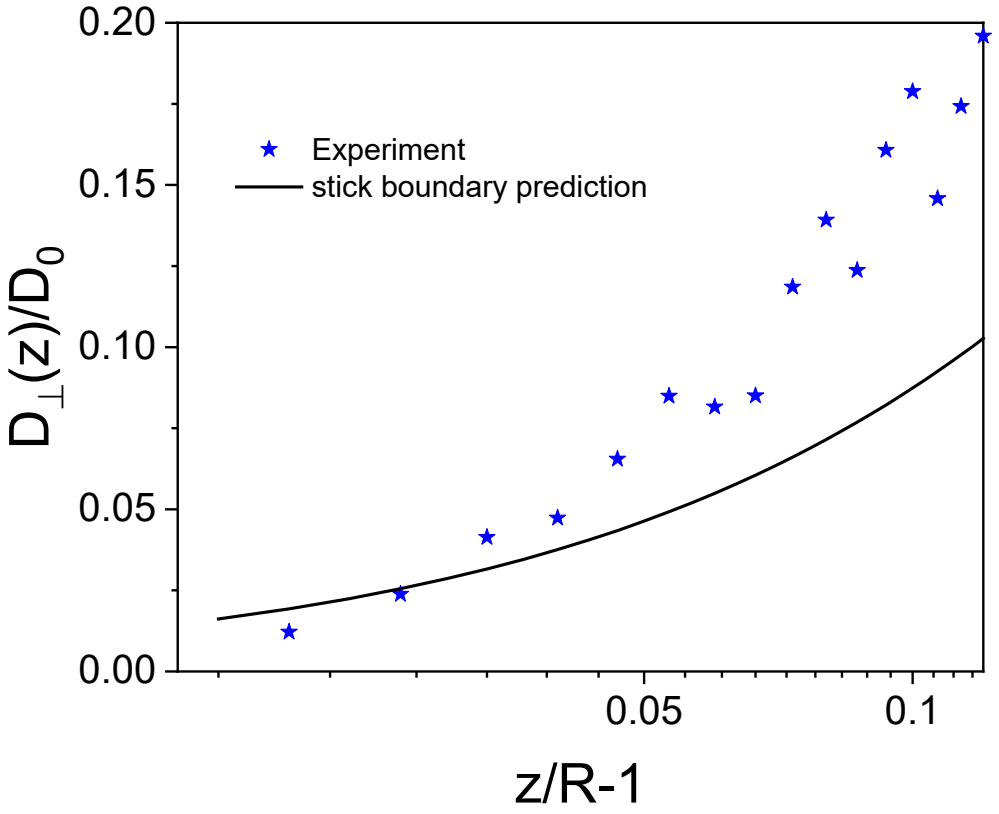
$$\phi_d = -A_d(\rho, L, R)\left(1 - \frac{h}{L}\right)^3$$





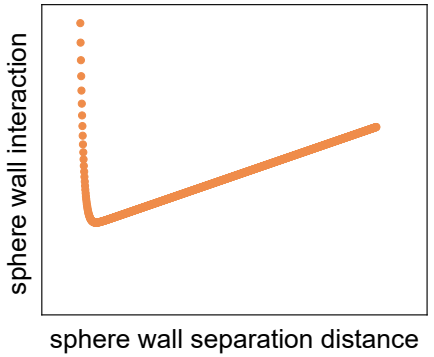
SIMULATION RESULTS: DYNAMIC PROPERTIES

Experimental data

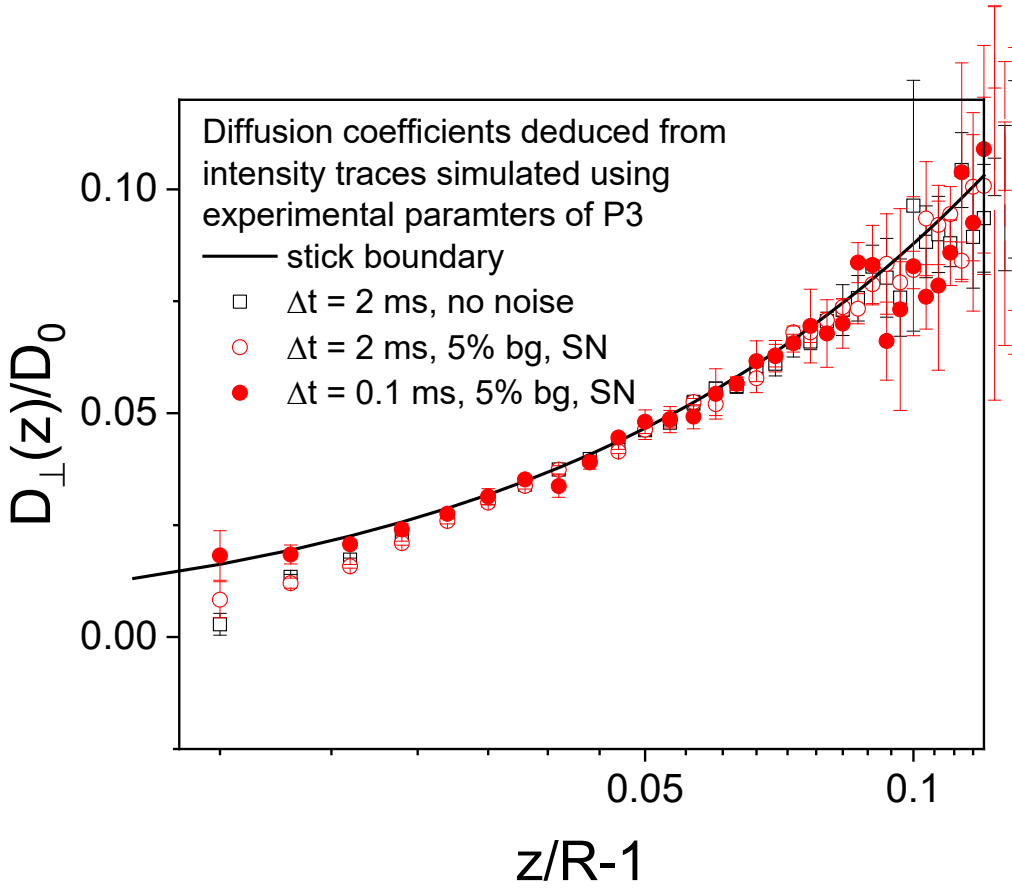


PS sphere
R = 2000 nm

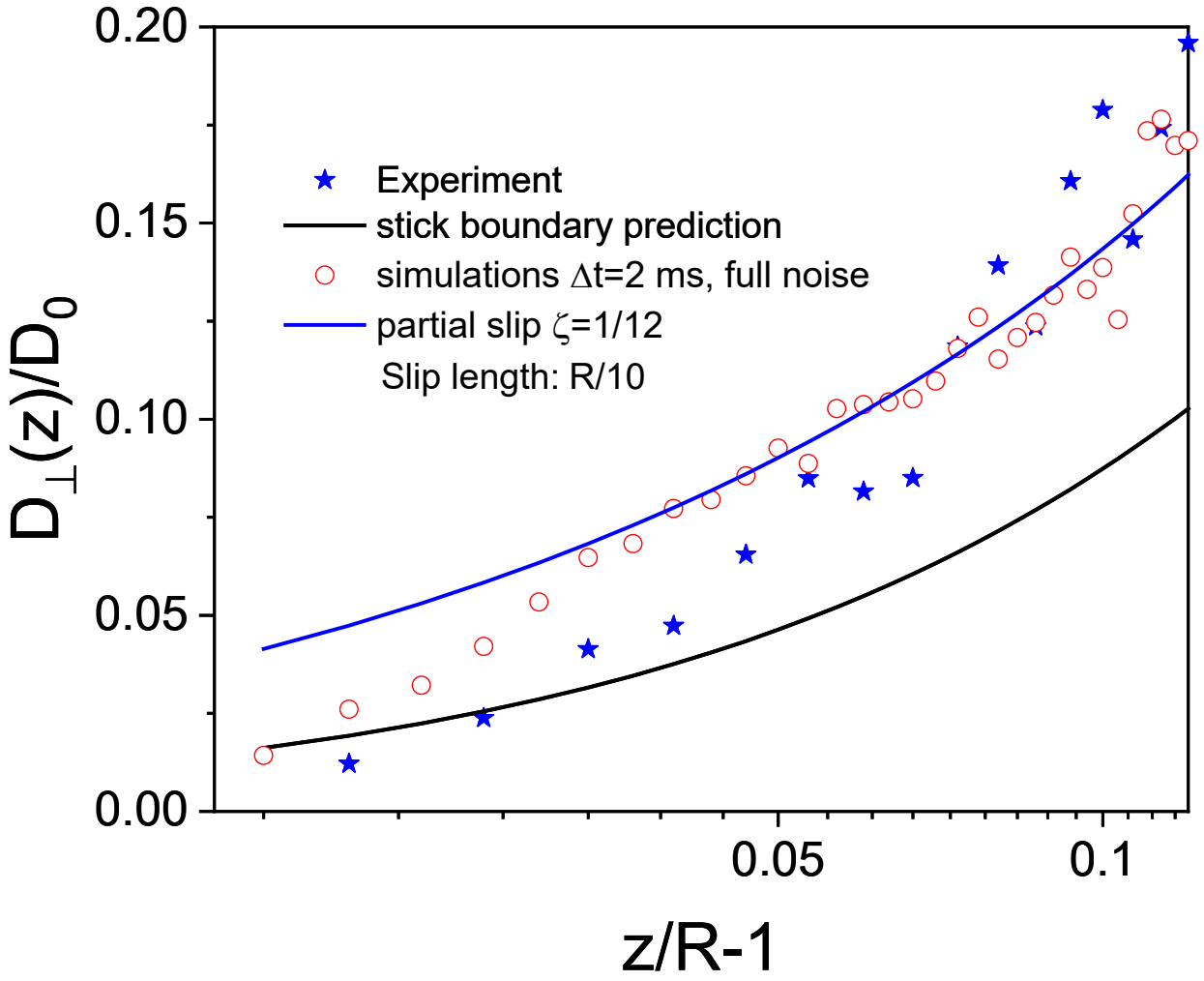
$$\phi(h) = \phi_{er} + \phi_g$$



simulated data



SIMULATION RESULTS: DYNAMIC PROPERTIES



CONCLUSIONS

TIRM: powerful method to measure interaction forces with unprecedented resolution

Inevitable sources of error

- detector shot noise: mainly effects static results
- finite sampling time: mainly impacts on the dynamic results

Requires careful selection of experimental parameters to obtain undistorted results

Rule of thumb: $\Delta t < \delta h \frac{6\pi\eta R}{\lambda^{-1}} \left(\frac{\partial \phi}{\partial h} \right)^{-1}_{\max}$ with $\lambda^{-1} = \frac{6z^2 - 10Rz + 4R^2}{6z^2 - 3Rz - R^2}$

Thank you