Tracking Single Particles using Surface Plasmon Leakage Radiation Speckle

Imperial College London

Joel Berk and Matthew R. Foreman

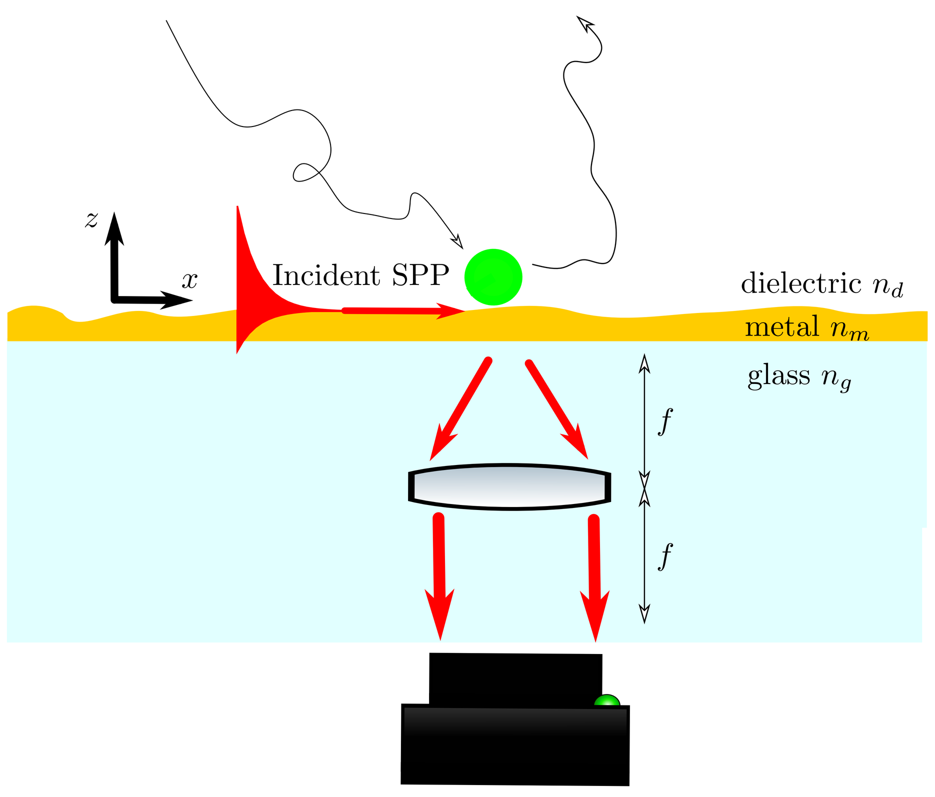
MOTIVATION

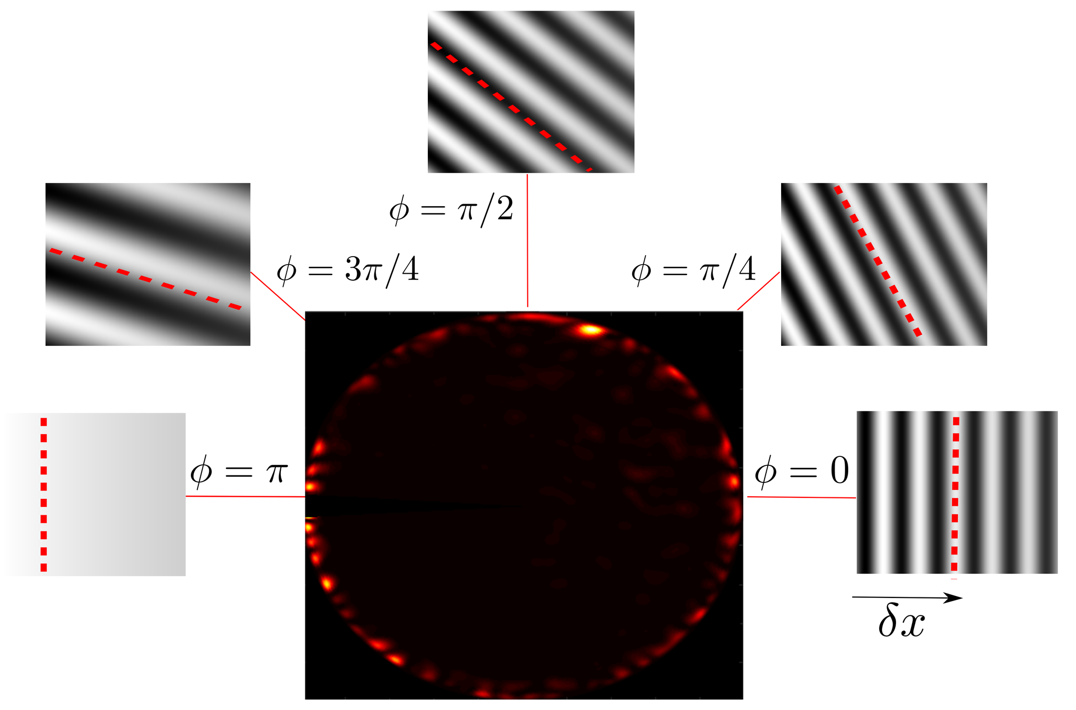
- **Detection and tracking of single nanometre scale biological molecules:** small particles interact only weakly with light
- **Enhance light-matter interaction using plasmonics:** confined surface modes give strong local fields[1]
- **Interference with strong background field to increase sensitivity:** Interferometric signals are sensitive to small phase perturbations[2]

Principle

- **Scattered light strongly confined to cone:** due to conservation of SPP momentum[3]
- **Random scattering by rough surface:** random interference of wavefronts gives speckle pattern
- **Light scattered by analyte particle has known phase (and amplitude) dependence on particle position:** fringe patterns at different directions, ϕ, on the cone as the analyte particle moves (assuming single scattering)
- **Random speckle phase:** unknown random offsets of fringe pattern, different for each ϕ
- **Eliminate unknown phase using 3 frames in particle trajectory**
- **Solve simultaneously the N equations for N pixels around the ring for analyte particle displacement between frames**

$$(\hat{\boldsymbol{r}}_{12}, \hat{\boldsymbol{r}}_{23}) = \underset{(\boldsymbol{r}_{12}, \boldsymbol{r}_{23})}{\arg\min} \sum_{j=1}^{N} \left(\frac{\boldsymbol{u}(\phi_j) \cdot \boldsymbol{\Delta}(\phi_j)}{|\boldsymbol{u}(\phi_j)|} \right)^2$$

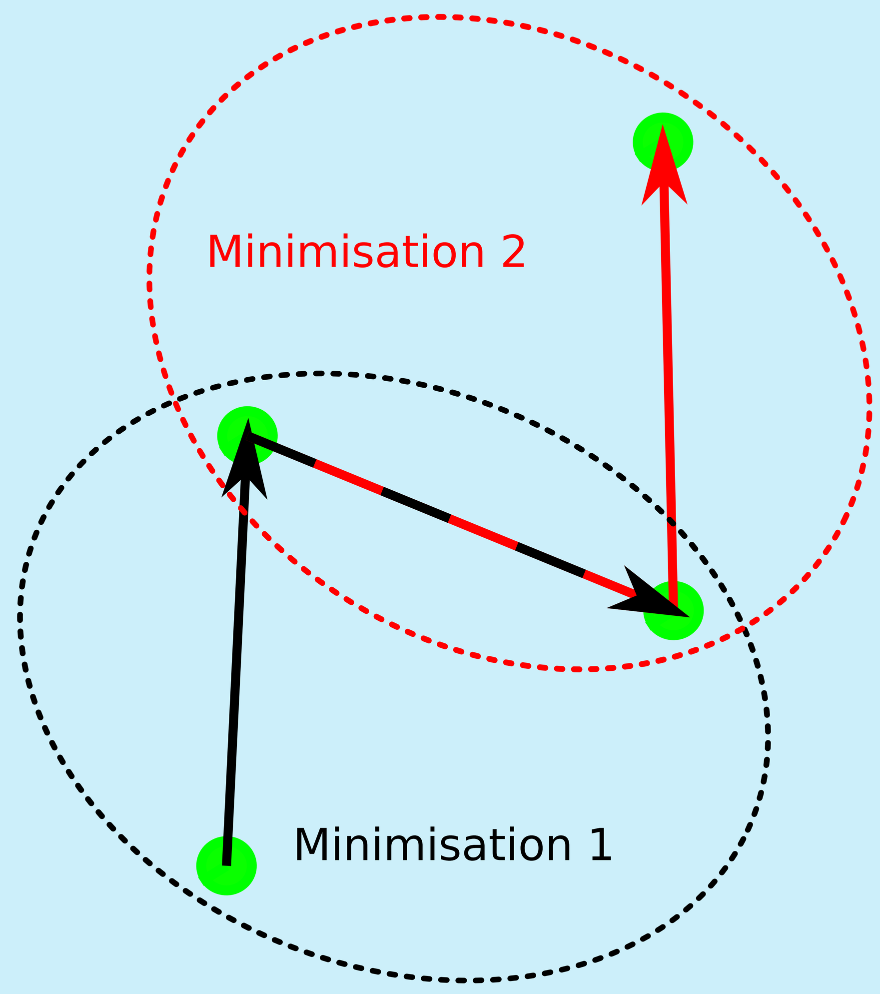




	Performance Metric	Shot Noise limit	'Dark' Noise limit
Dark Field	SNR $=$ dSNR	$\sqrt{N_s}$	$N_s/\sqrt{N_d} \ll 1$
	SBR	$N_s/N_d \gg 1$	$N_s/N_d \ll 1$
Interference	SNR	$\sqrt{N_b} \gg 1$	$\sqrt{N_b} \gg 1$
	SBR	$\sqrt{N_s/N_b} \ll 1$	$\sqrt{N_s/N_b} \ll 1$
	dSNR	$\sqrt{N_s}$	$\sqrt{N_s}$

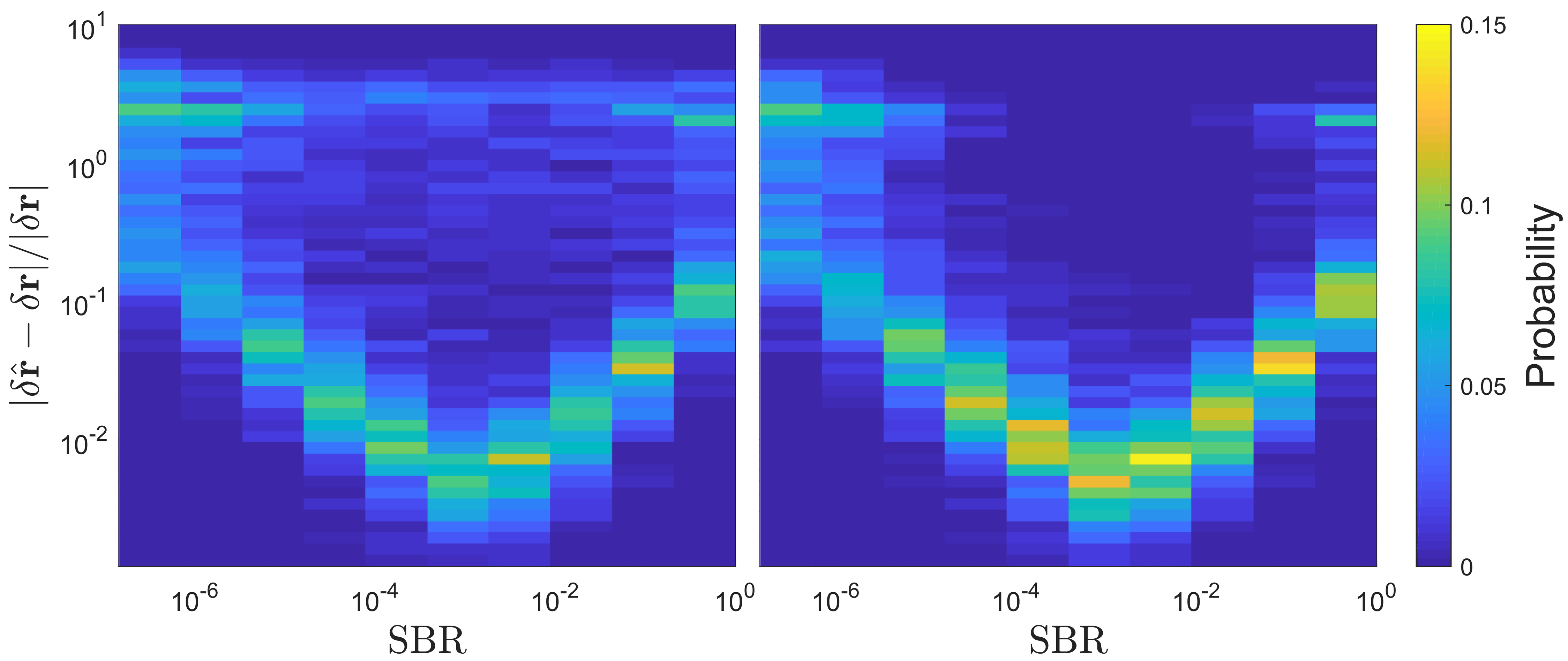
Consistency Check

- **Global least squares minimisation:** may converge to local minimum
- **Require consistency of step estimates:** run minimisation procedure with new start points until consistent trajectory achieved
- **Potential sign ambiguity:** symmetry of system means exact opposite transverse steps give same phase shift
- **Flip transverse steps estimates if it improves consistency**



Results

- **Results from simulations:** point scatterer undergoing random walk with 90nm step size
- **Error in step estimate depends on the fringe amplitude relative to:**
  A) the background speckle intensity (signal to background ratio, SBR)
  B) the shot noise level (differential signal to noise ratio, dSNR)
- **Two regimes where algorithm performs poorly:**
  A) SBR≥1, directly scattered intensity no longer negligible relative to interference
  B) low dSNR, noise levels comparable to fringe amplitude
- **Optimal working regime:** achieves errors of order 1%, corresponding to subnanometre precision



1. J. Homola, S. S. Yee, and G. Gauglitz, “Surface plasmon resonance sensors: review,” Sensors Actuators B54, 3–15 (1999).
2. R. W. Taylor and V. Sandoghdar, “Interferometric Scattering Microscopy: Seeing Single Nanoparticles and Molecules via Rayleigh Scattering” Nano Lett.19, 4827–4835 (2019).
3. S. A. Maier, "Plasmonics: Fundamentals and Applications" (Springer, 2007), 1st ed.