Field correlations in surface plasmon speckle

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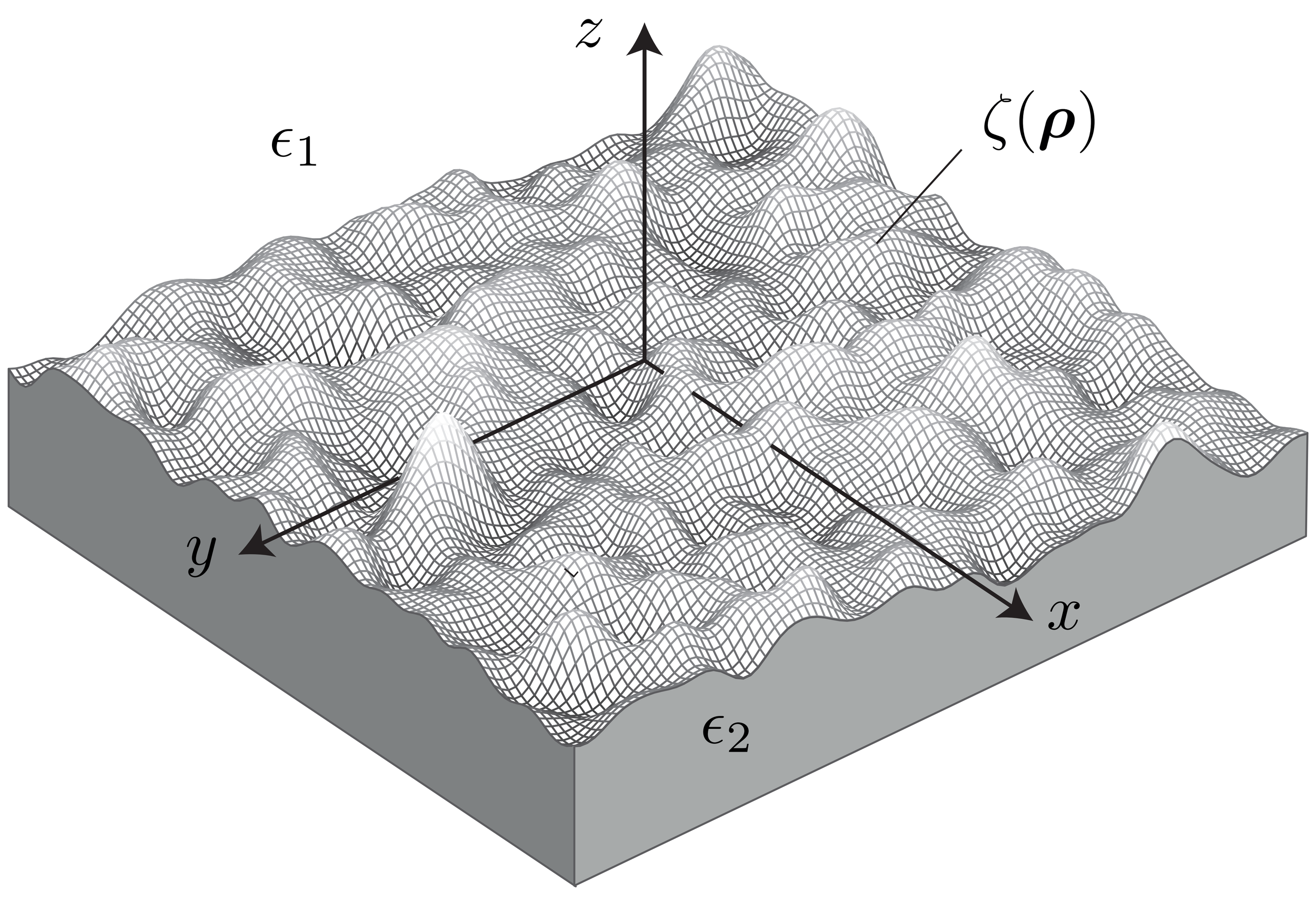
Introduction

- **Inhomogenous scattering media:** can give rise to random interference patterns, or speckle, in coherent optical systems. Statistical properties of speckle can be exploited for applications including metrology, wave front sensing, stellar characterisation and correlation spectroscopy.
- **Intensity and phase correlations:** give rise to interesting effects such as the memory effect, coherent back scattering and Anderson localisation. The analytic form of these correlations do not depend on the nature of the scattering medium.
- **Evanescent components in near field speckle:** give rise to non-universal behaviour and sub-wavelength correlations.
- **Resonant surface waves:** We have studied the effects that resonant surface waves surface plasmon polaritons can have on field correlations near the surface of randomly rough metallic surfaces.

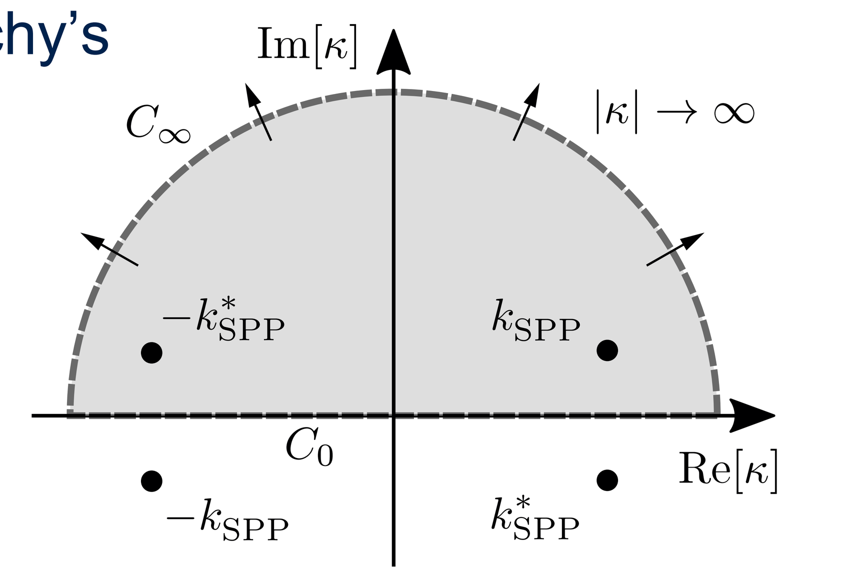
Modelling surface plasmon-polaritons on rough surfaces



- **Surface roughness:** described by effective surface current $\mathbf{J}(\mathbf{r}) = -i\omega\delta\epsilon(\mathbf{r})\mathbf{E}_0(\mathbf{r})$
- **Correlations in roughness induced field fluctuations:** described by two point correlation matrix which derives from SPP Greens tensor:

$$\mathbb{W}(\mathbf{r}_1,\mathbf{r}_2) = \langle\delta\mathbf{E}^*(\mathbf{r}_1)\delta\mathbf{E}^T(\mathbf{r}_2)\rangle = \omega^2\mu_0^2\iint \mathbb{G}^*(\mathbf{r}_1,\mathbf{r}_3)\mathbb{W}_J(\mathbf{r}_3,\mathbf{r}_4)\mathbb{G}^T(\mathbf{r}_2,\mathbf{r}_4)d\mathbf{r}_3 d\mathbf{r}_4$$

- **Closed form expressions:** derived using Cauchy's residue theorem and Jordan's lemma
- **Assumptions:**
  - single scattering regime
  - surface roughness and source fields are statistically isotropic and homogeneous in a transverse plane

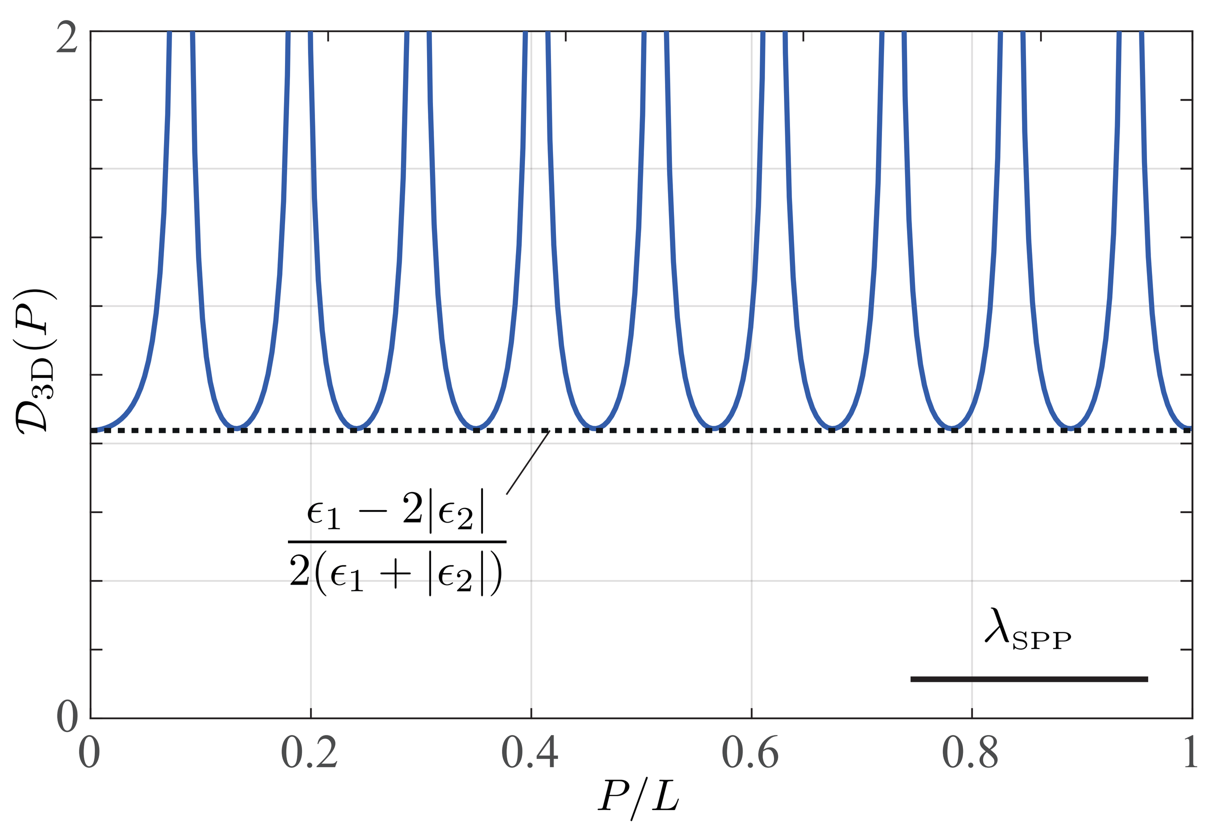


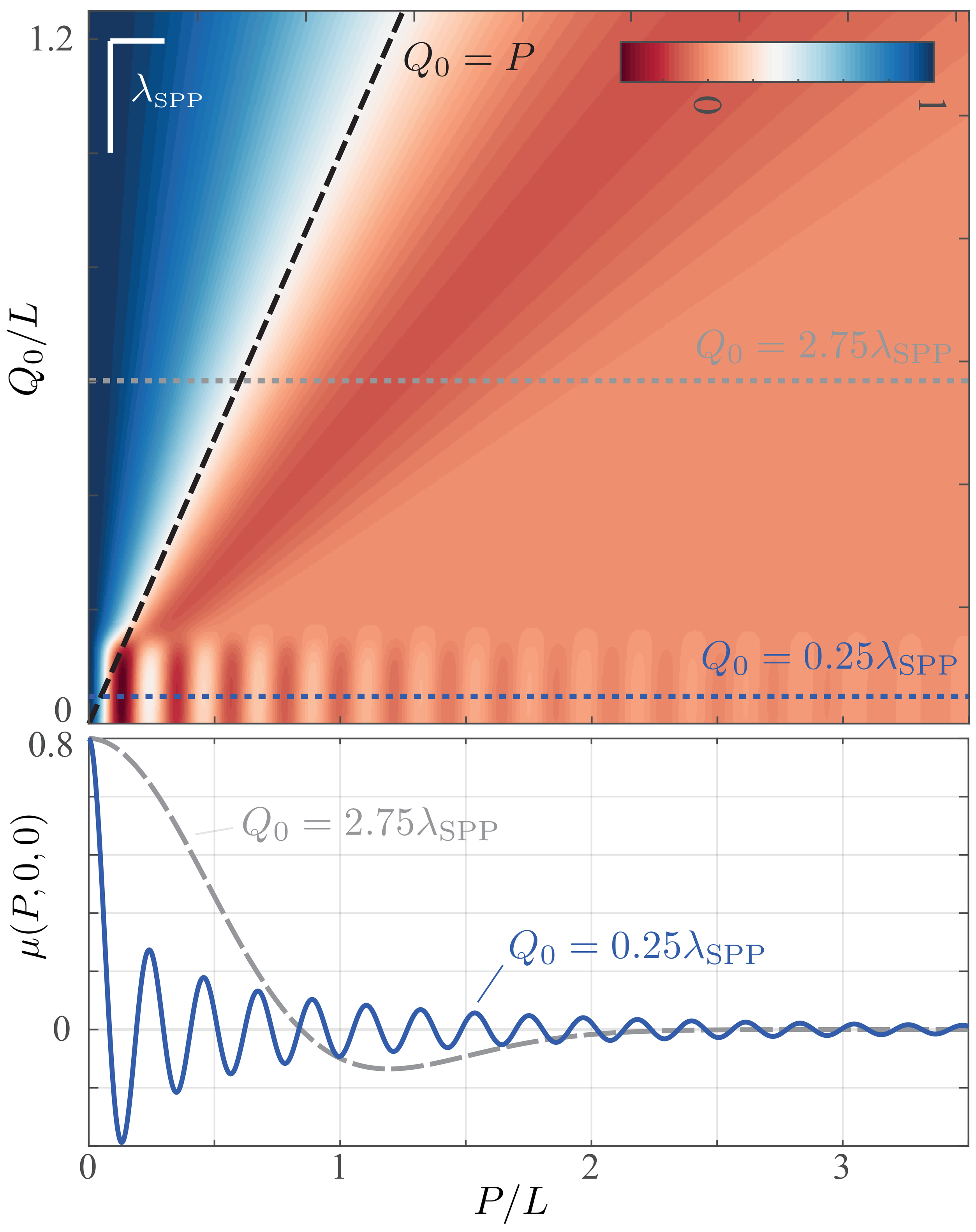
Near field polarisation and coherence properties

- **Degree of cross polarisation:** gives interdependence of field components

$$\mathcal{D}_{n\mathrm{D}}^2 = \left(3-\frac{n}{2}\right)\left[\frac{\|\mathbb{W}(\mathbf{P},z_1,z_2)\|_F^2}{\mathrm{tr}[\mathbb{W}(\mathbf{P},z_1,z_2)]^2} - \frac{1}{n}\right]$$

- independent of axial distance
- lower bounded by 3D DOP and fixed by material properties only
- TM nature of SPP gives fixed relation between 2D and 3D DOPs: $\mathcal{D}_{2\mathrm{D}}^{\parallel} = 0$ and: $3[\mathcal{D}_{2\mathrm{D}}^{\perp}(\mathbf{0})]^2 = 4[\mathcal{D}_{3\mathrm{D}}(\mathbf{0})]^2 - 1$





- **Degree of coherence:** quantifies fringe visibility in plasmonic interferometric measurements

$$\mu = \frac{\mathrm{tr}[\mathbb{W}(\mathbf{P},z_0,z_0)]}{\mathrm{tr}[\mathbb{W}(\mathbf{0},0,0)]}$$

- decays exponentially with axial distance
- independent of the off-diagonal elements of the surface/source correlation matrix $\mathbb{W}_J(\mathbf{r}_1,\mathbf{r}_2)$
- DOC adopts universal form when metal losses are low and surface correlation length is short

$$\mu \approx \frac{e^{-k_{\mathrm{SPP}}z_0}}{2}\left[H_0^{(1)}(k_{\mathrm{SPP}}P) - H_0^{(1)}(-k_{\mathrm{SPP}}^*P)\right]$$

- Non-universal form of DOC dominated by surface correlation function
- Fluctuation length of DOC limited by SPP wavelength

References

- M. R. Foreman, arXiV:1901.00681, (2019).
- R. Carminati, Phys. Rev. A 81, 053804 (2010).
- S. Ponomarenko and E. Wolf, Phys. Rev. E 65, 016602 (2002).

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Conclusions

- **Closed form analytic expressions:** for the correlation matrix for roughness induced SPP field fluctuations derived.
- **Near field polarisation and coherence properties:** analysed using metrics accounting for three dimensional nature of near fields.
- **Non universal behaviour:** in the form of the DOC results when losses are large or surface correlation length is long.