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Fisher Information Dark States and plasmonic resonances

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Abstract. In this talk, we discuss the effect of plasmonic resonances on the Fisher information in the far field. We consider a metallic nanowire embedded in a silicon substrate, illuminated by a dark-field focused spot, and we investigate how its position can be estimated from the scattered far-field intensities. The Fisher information is computed for both lateral and longitudinal displacements of the nanowire, and the dependence on the illumination frequency is analyzed. We compute the complex resonance frequencies of the nanowires and show that frequencies near the real part of the plasmonic resonance frequency enhance the Fisher information. However, at the resonance frequency itself, the Fisher information drops sharply, leading to an *Information Dark State* in which the position of the nanowire becomes nearly undetectable. This effect is analyzed and illustrated for both gold and silver nanowires.

1 Introduction

Inverse (electromagnetic) problems play a key role in many modern applications such as biomedical imaging or semiconductor manufacturing. In most of these problems, an incidence beam illuminates an unknown target, and the intensity of the scattered light is measured at a detector in the far-field. The aim is to estimate the properties of the unknown target from the far-field measurements.

The measurements in the far-field are always subject to Poisson shot noise, hence there is a fundamental limit to the precision of the estimates. This limit is quantified by the Cramér-Rao lower bound (CRLB), which gives us a lower bound on the precision of a minimum-variance unbiased estimator based on the measured intensities. A lower CRLB means a more precise estimator. The CRLB is given by the reciprocal of the square root of the Fisher information, so a high Fisher information means a low CRLB.

The CRLB has been studied in various optical applications, including ptychography [1], coherent diffractive imaging [2], and wavefront shaping [3]. However, the influence of the target's intrinsic optical properties (specifically the presence of plasmonic resonances) on the CRLB has not yet been explored.

In this work, we study how plasmonic resonances affect the Fisher information in optical position sensing. We focus on a metallic nanowire in a silicon substrate, and compute the Fisher information from far-field intensity measurements under dark-field illumination.

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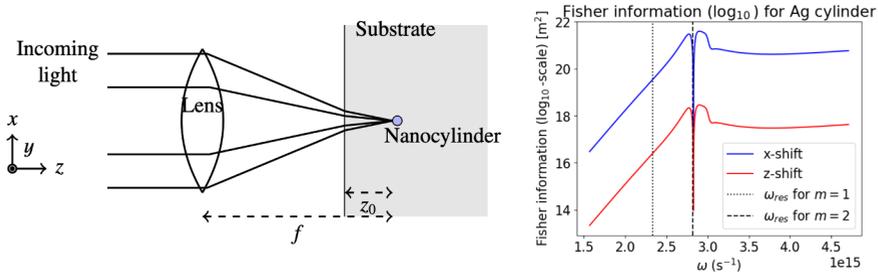


Figure 1. Left: A sketch of the illumination of the cylinder inside the nanowire. **Right:** Fisher information (in log₁₀-scale) for an x -shift and a z -shift, as a function of frequency ω of the incidence field. The vertical dotted line is at the real part of the dipole resonance frequency, and the dashed vertical line is at the real part of the quadrupole resonance frequency.

2 Model of the scattering

A two-dimensional model for the illumination of a metallic nanowire is defined. See Figure 1. The nanowire is assumed to be infinitely long, embedded in a silicon substrate and with axis parallel to the y -axis. The radius of the nanowire is kept at $a = 20$ nm. The material of the nanowire is varied between silver and gold. Incidence light transmits through the air-silicon interface, then focuses at the center of the nanowire, where the two-dimensional scattering of the beam by the nanowire is computed. The incidence field is TM polarized, and a dark-field illumination is used.

The Fisher information for a displacement of the nanowire in both the x -direction and in the z -direction are computed as functions of frequency ω . The computations are done analytically.

3 Key findings

For a silver nanowire, the result is in Figure 1. We find that the Fisher information peaks close to the quadrupole resonance frequency. However, at the resonance frequency itself, a sharp dip in the Fisher information occurs. This is an *Information Dark State*.

In this talk, the phenomenon is explained by investigating both the electric and magnetic field components of the scattered field.

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