Sensing the position of a single scatterer in opaque media using Mutual Extinction and Transparency

Minh Duy Truong, Alfredo Rates, Ad Lagendijk, Willem L. Vos

Complex Photonic Systems (COPS), MESA + Institute for Nanotechnology, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands

ABSTRACT

Traditional scattering experiments are associated with sending a single beam on a target. The detailed structure of the target including the positions of all scatterers is encoded in the characteristics of the scattered waves. However, when a medium becomes opaque, usual single scattering (Fourier) approaches breaks down and only limited information is available by, e.g., diffusing wave spectroscopy. Recently, the development of multiple-beam techniques, e.g., wavefront shaping, has opened more potential in the research of opaque samples. Different from the case of a single incident wave, the interference of multiple beams gives rise to a new phenomenon called "Mutual Extinction and Transparency (MET)" [1].

Here, we conjecture that Mutual Extinction with 2 incident beams is a promising technique to detect the movement of a dipole in a sample of multiple stable dipoles. The underlying idea is that the cross-interference information of 2 beams is more sensitive to changes of the scatterer located deep within the sample than conventional scattering methods. For comparison, we perform exact calculations of the sensitivity of Mutual Extinction (from 2 beams) and the differential cross-section (from 1 beam) in response to the displacement of 1 dipole. Our numerical results confirm that Mutual Extinction is indeed more sensitive, thus, a better tool (than traditional 1-beam techniques) to locate a single scatterer inside a multiple scattering sample.

INTRODUCTION

❖ Conventional methods: 1 beam

$$I_1 \propto |\psi_{\text{scat},1}|^2 = \psi^*_{\text{scat},1}\psi_{\text{scat},1} \propto |f(\mathbf{k}_{\text{out}}, \mathbf{k}_{\text{in}})|^2$$

f: scattering amplitude

❖ Mutual Extinction: 2 beams

$$I_2 \propto \psi^*_{\text{in},2}\psi_{\text{scat},1} \propto f(\mathbf{k}_{\text{out}}, \mathbf{k}_{\text{in}})$$

"Amplitude vs Intensity"

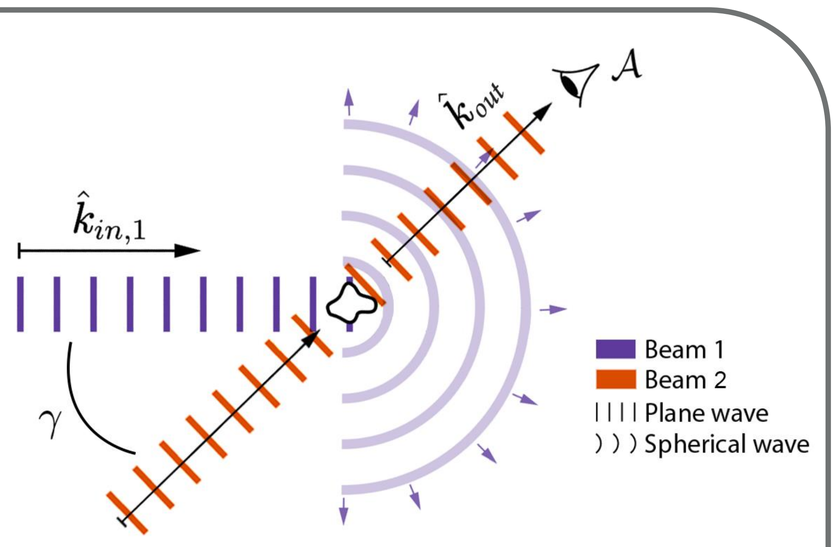

Fig 1: Conceptual summary of Mutual Extinction & Transparency.

APPLICATIONS

Cross-interference of multiple beams > 1-beam scattering methods

❖ Determine the shape (nano-scale)
❖ Detect concentration of matter in the air/liquid
❖ Sense a scatterer in opaque media (needle in a haystack)

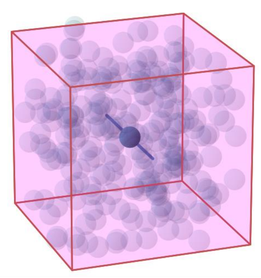

Fig 2: How to sense the position of a single scatterer in opaque media?

SENSITIVITY OF MET

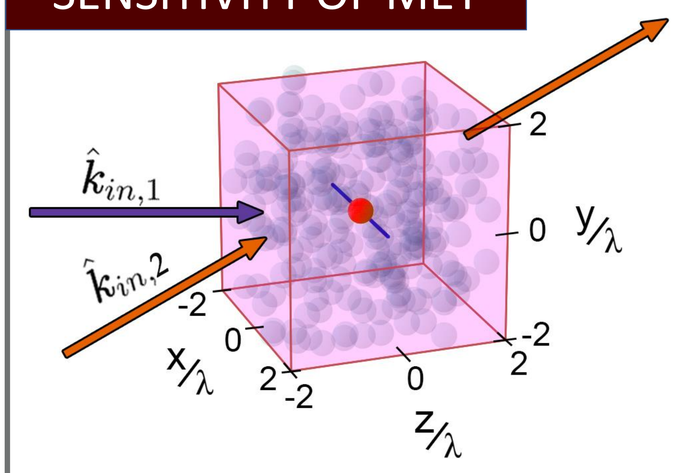

Fig 3: Mutual Extinction & Transparency setup to detect a moving scatterer. There are N = 250 dipoles in the box.

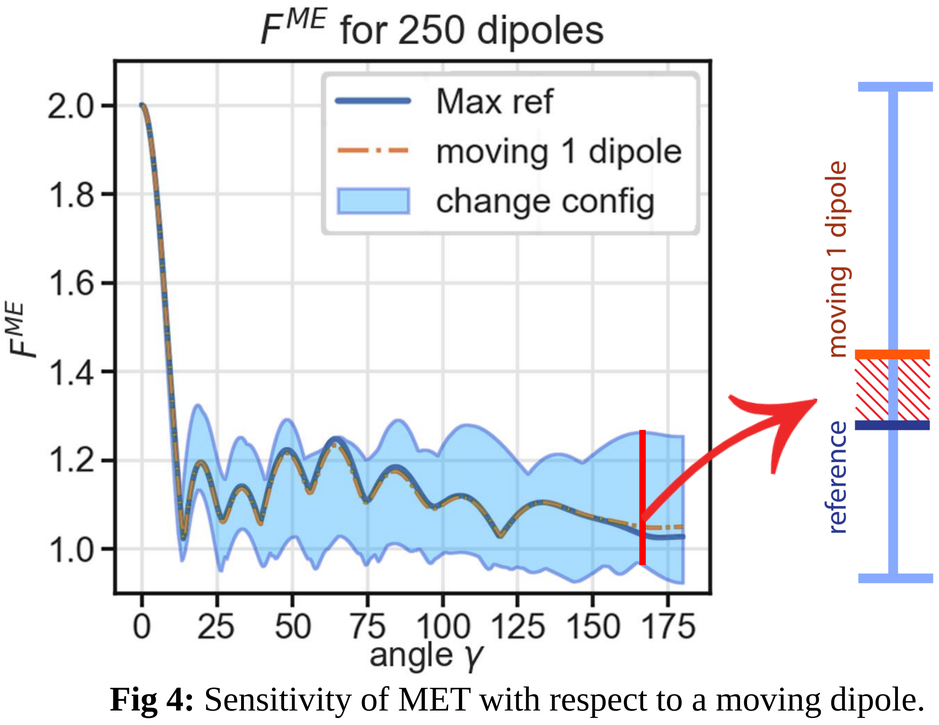

Fig 4: Sensitivity of MET with respect to a moving dipole.

❖ Normalized deviation of Mutual Extinction & Transparency:

$$\tilde{\delta}F^{\text{ME}} := \frac{|F^{\text{ME}} - F^{\text{ME}}_{\text{ref}}|}{F^{\text{ME}}_{\text{sup}} - F^{\text{ME}}_{\text{inf}}} > \frac{1}{N_{\text{dipole}}}$$

SENSING A MOVING SCATTERER

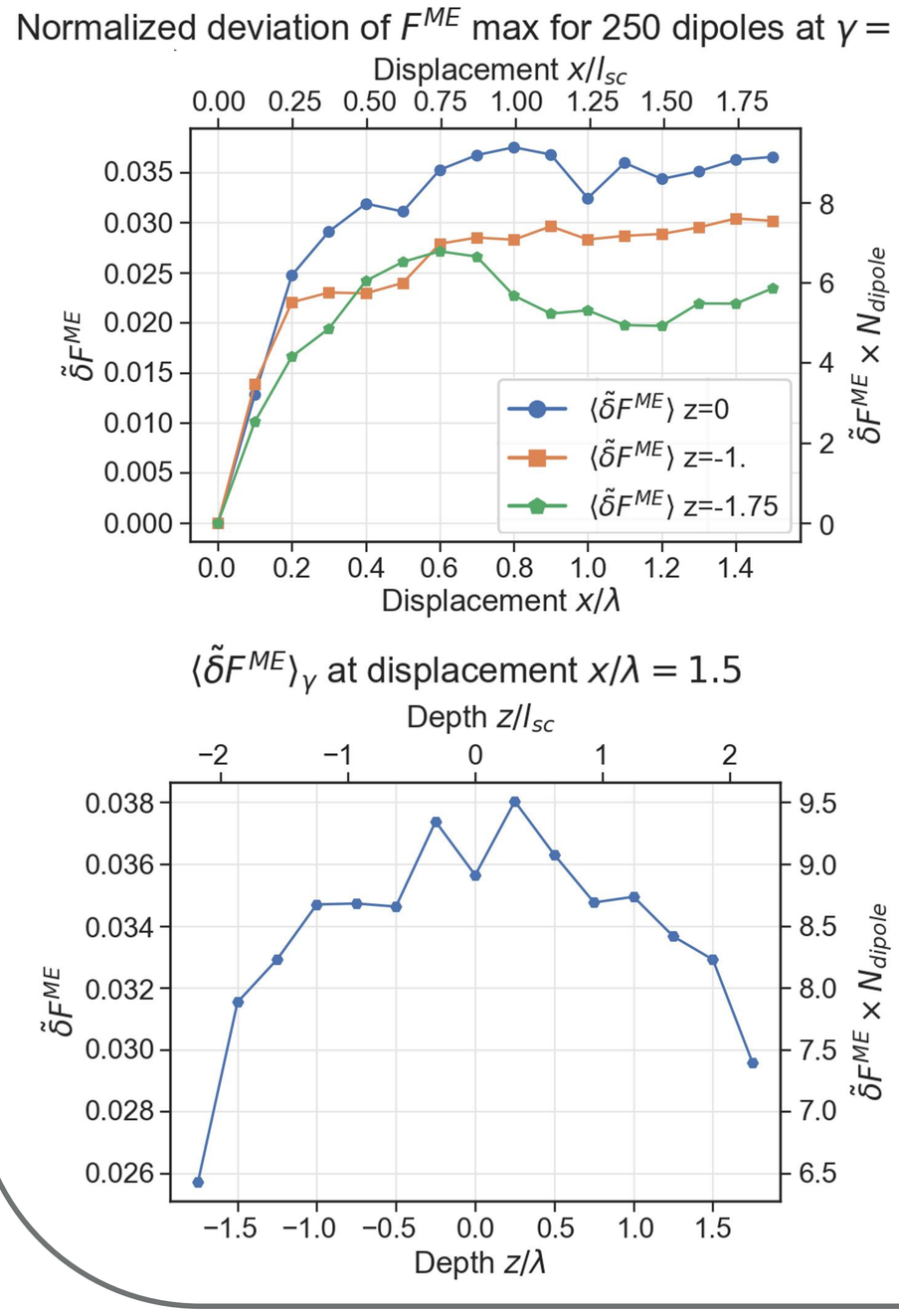

Fig 5: Normalized deviation of Mutual Extinction & Transparency with respect to the displacement of dipole.

Fig 6: Normalized deviation of Mutual Extinction & Transparency at different depths. Mutual Extinction is indeed more sensitive.

MET is more sensitive to the motion of the dipole located closer to the center

REFERENCES

[1] A. Lagendijk, A. P. Mosk, and W. L. Vos, EPL 130, 34002 (2020)
[2] A. Rates, A. Lagendijk, O. Akdemir, A. P. Mosk, and W. L. Vos, Phys. Rev. A 104, 043515 (2021)

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