Emanuele Corsaro

ANALOG CIRCUIT EMULATION OF ELECTROMAGNETIC SCATTERING

Tutor: prof. Carlo Forestiere

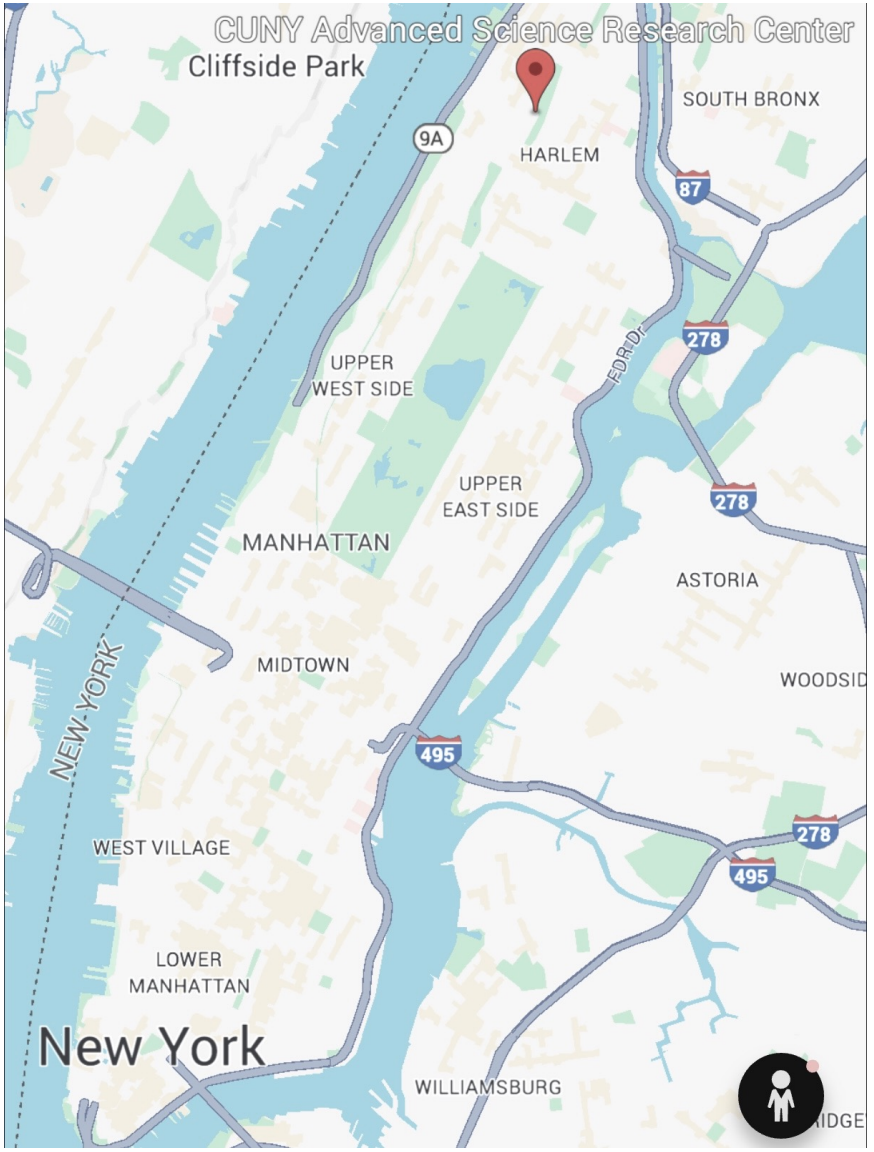
Cycle: XXXIX Year: II

Candidate's information

- MSc in **Electrical Engineering** (2023) from the University of Naples "Federico II". Thesis: *Fast Multipole Approach for the Solution of Electromagnetic Multiscale Problems*
- PhD start date: 01 November 2023
- Scholarship type: DIETI PRIN
- Research group/laboratory: Nanophotonics Group[1] & Alù Lab[2]
- Period Abroad: Feb 2025 – Present
- Host: Prof. **Andrea Alù**

[1]Dept. Of Electrical Engineering and Information Technology @(UNINA, NA, IT)

[2]Photonics Initiative – Advanced Science Research Center @(GC CUNY, NY, USA)



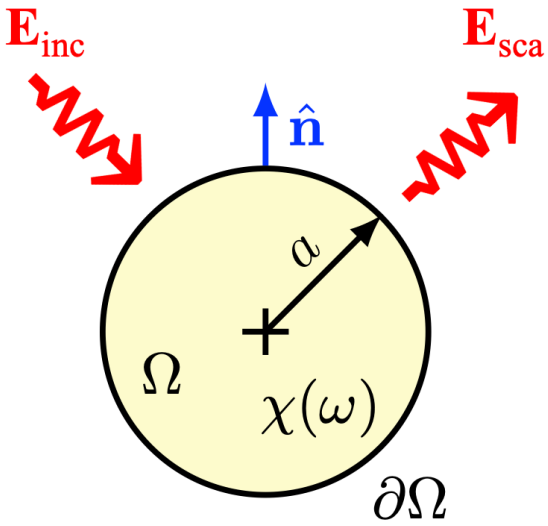
Summary of study activities

Conferences

- **ETOPIM13**: 13° International Conference on Elastic, Electrical Transport, and Optical Properties of Inhomogeneous Media (16-20 Jun, New York, NY, USA)

- **SIMONS Collaboration on Extreme Wave Phenomena Based on Symmetries** Annual Meeting (22-24 Oct, New York, NY, USA)

Research areas



- I am in the *Elettrotecnica* group, focused on Theoretical and Computational **Electrodynamics**
- Currently focused on **electromagnetic scattering** involving linear, non-linear and time-varying materials, developing **equivalent circuit** models as the fundamental approach
- **Doctoral research**: Investigating Extreme wave phenomena in linear and non-linear scattering
- **Collaborations**: Prof. **Andrea Alù** (City University of New York)

Research areas

- I am also focused in investigating **Exceptional Points of Degeneracy** (EPDs) in EM Scattering
- **Collaborations**: Prof. **Filippo Capolino** (University of California, Irvine)

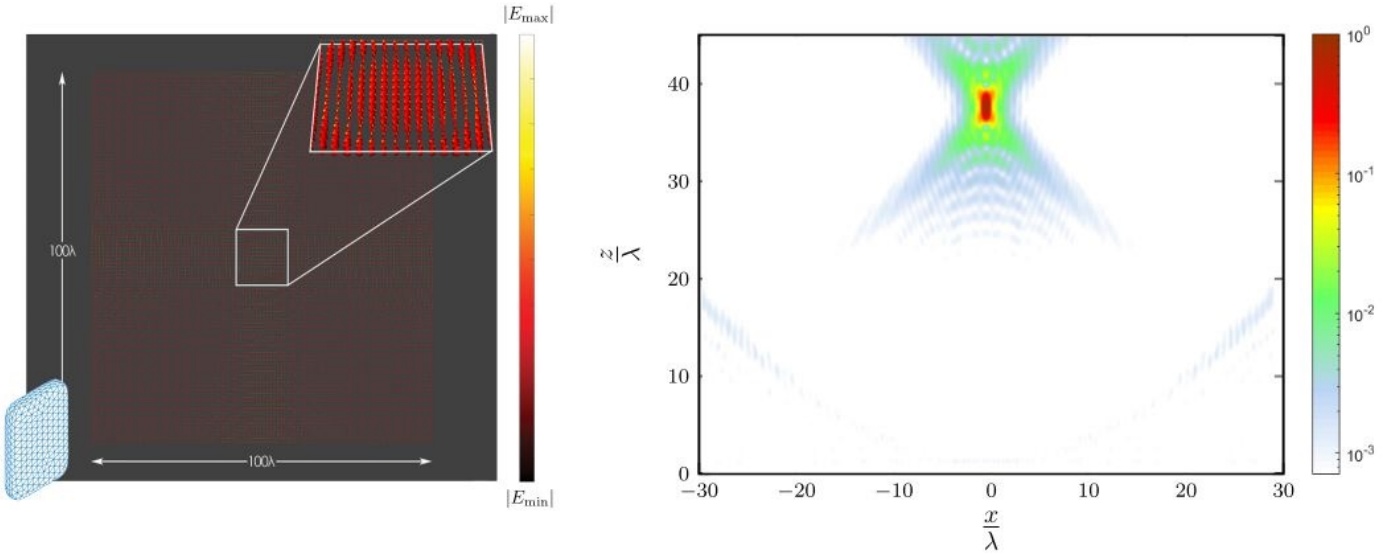
Research areas

- **Fast Computational Methods** for the electromagnetic scattering from large **metasurfaces** and **metalenses** [1]

Multilevel Fast Multipole Algorithm for Electromagnetic Scattering by Large Metasurfaces using Static Mode Representation

Publisher: IEEE | Cite This | PDF

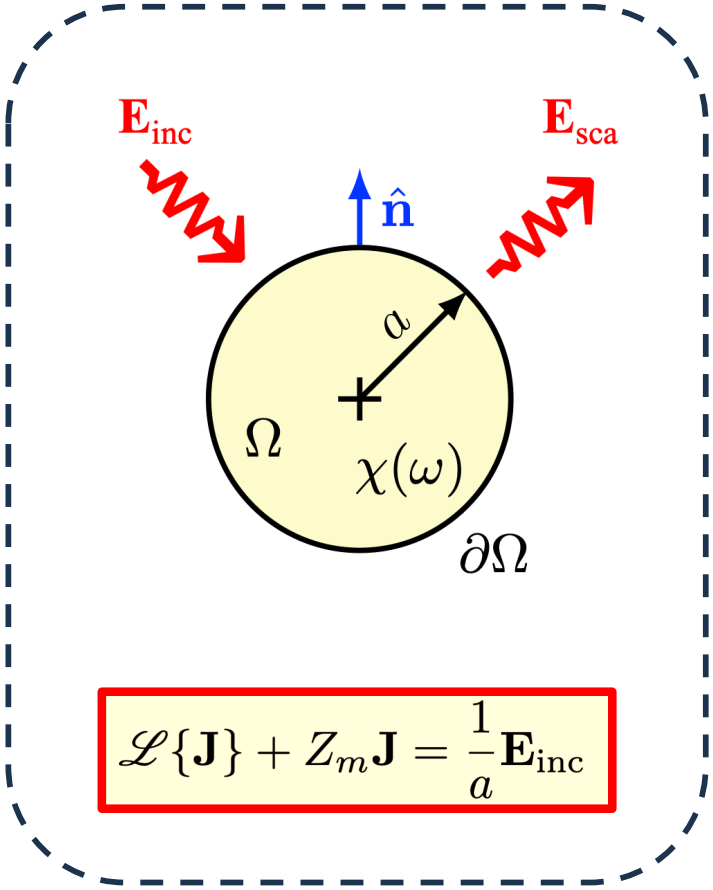
Emanuele Corsaro ; Giovanni Miano ; Antonello Tamburrino ; Salvatore Ventre ; Carlo Forestiere **All Authors**



[1] E. Corsaro, G. Miano, A. Tamburrino, S. Ventre and C. Forestiere, "Multilevel Fast Multipole Algorithm for Electromagnetic Scattering by Large Metasurfaces using Static Mode Representation," in *IEEE Transactions on Antennas and Propagation*

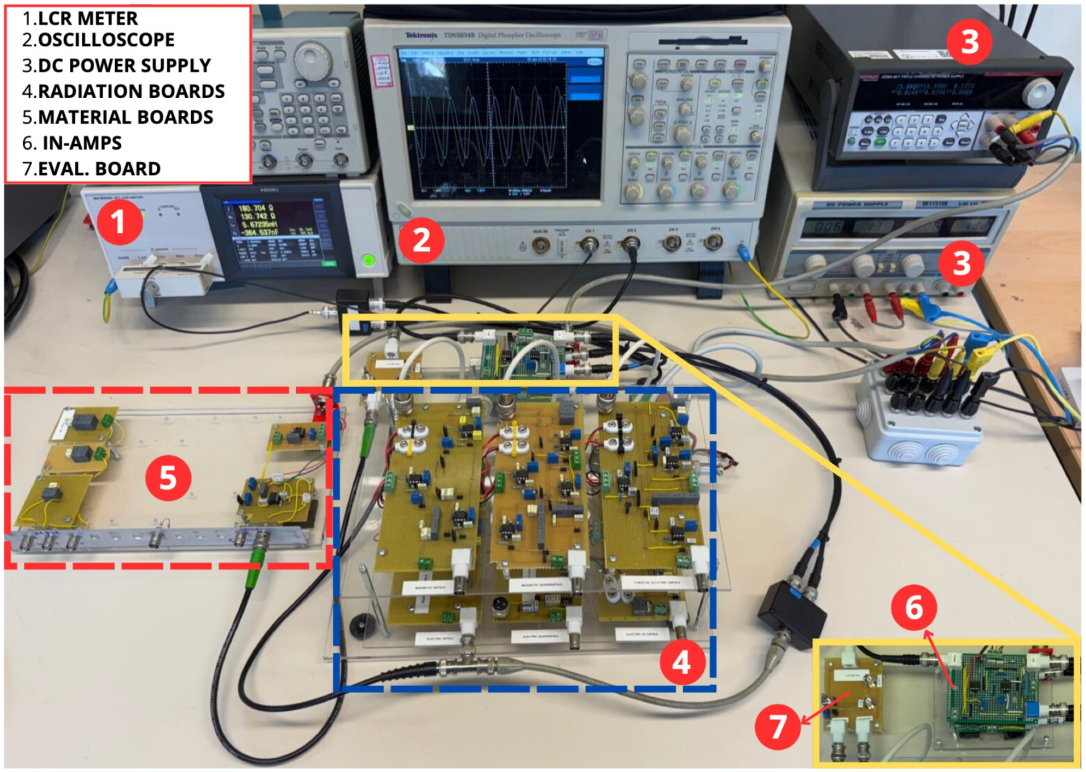
Research results

Mie Scattering Analog Circuit Emulator



$$\mathscr{L}\{\mathbf{J}\} + Z_m \mathbf{J} = \frac{1}{a}\mathbf{E}_{\text{inc}}$$

$\Longleftrightarrow$



$$\mathscr{L}\{\mathbf{J}\}(\mathbf{r}) := \frac{\zeta_0}{jk_0 a}\nabla_{\mathbf{r}} \oint_{\partial\Omega} \frac{e^{-jk_0|\mathbf{r}-\mathbf{r}'|}}{4\pi|\mathbf{r}-\mathbf{r}'|}\mathbf{J}(\mathbf{r}')\cdot\hat{\mathbf{n}}(\mathbf{r}')\,\mathrm{d}S' + jk_0\zeta_0\frac{1}{a}\int_{\Omega}\frac{e^{-jk_0|\mathbf{r}-\mathbf{r}'|}}{4\pi|\mathbf{r}-\mathbf{r}'|}\mathbf{J}(\mathbf{r}')\,\mathrm{d}\Omega'$$

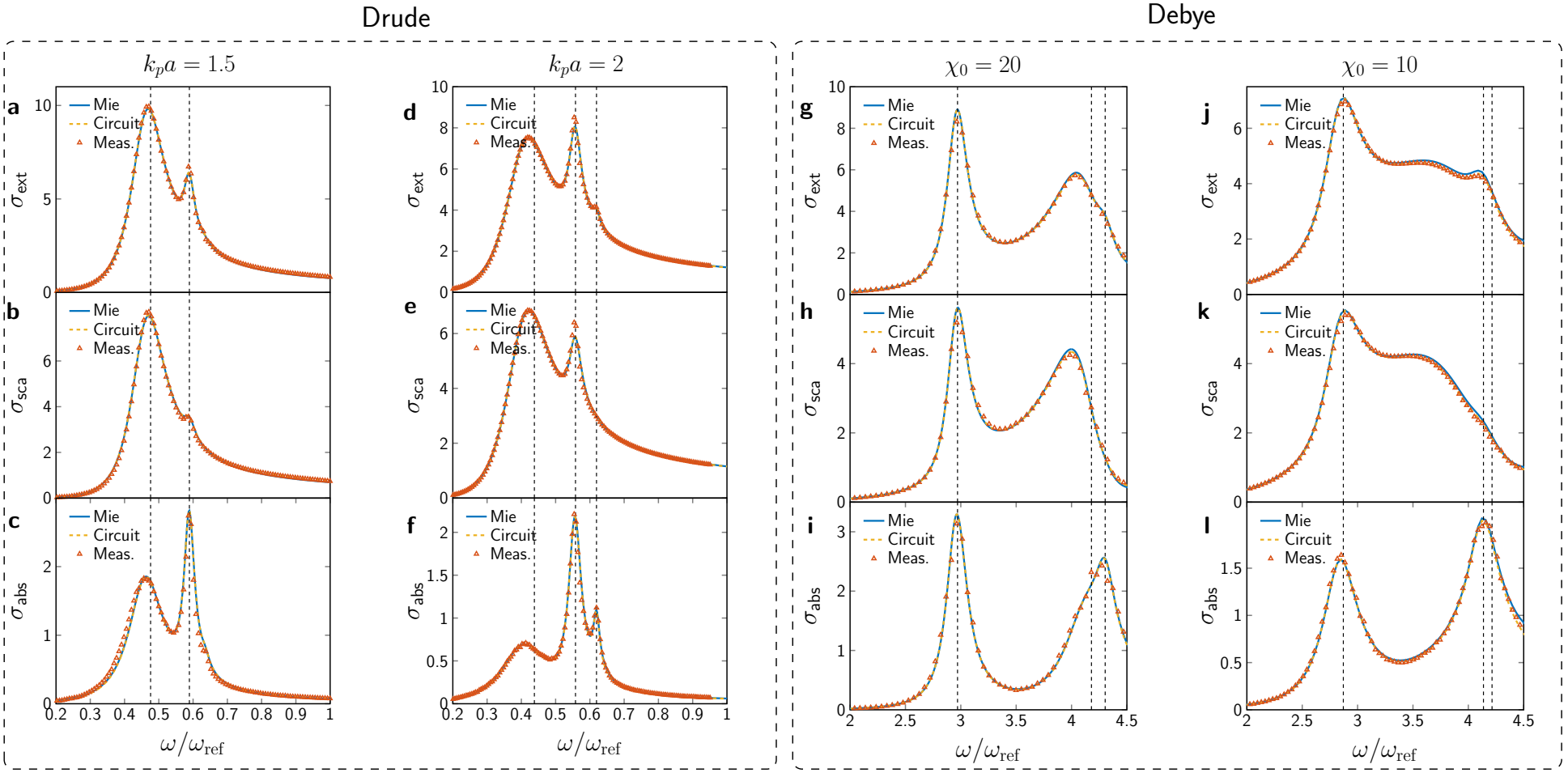
Research results

Mie Scattering Analog Circuit Emulator

- We introduce and experimentally validate an **analog circuit emulator** of Mie scattering.
- **Modular architecture**: excitation conditions are specified by generators and filters, whereas distinct passive networks capture material dispersion and radiative properties.
- **One-to-one correspondence** between the average powers scattered, absorbed, and extinguished by the dispersive sphere and the active power absorbed or supplied by distinct circuit stages, yielding a **circuit-level realization** of the optical theorem.
- A **rigorous** framework to explore **resonances** and **interference** effects, and to rapidly prototype **dispersion-engineered** scatterers, enabling bandwidth and lineshape control.

Research results

Mie Scattering Analog Circuit Emulator



Comparison of the extinction (σ_{ext}), scattering (σ_{sca}), and absorption (σ_{abs}) efficiencies obtained from Mie theory (blue solid line), circuit simulation (yellow dashed line), and experimental measurements (red triangles) as functions of the normalized frequency ω/ω_{ref} .

Research results

Exceptional Points in the Scattering Resonances of a Sphere Dimer

- Exceptional Points of Degeneracy (EPDs) are **points** in the parameter space of a non-Hermitian operator, at which two (or more) eigenvalues and their corresponding eigenvectors simultaneously **coalesce.**
- **Proof of Concept:** Eigenvalue problem that depends on a parameter θ

$$\mathscr{H}(\vartheta)\mathbf{u}(\vartheta) = \lambda(\vartheta)\mathbf{u}(\vartheta)$$

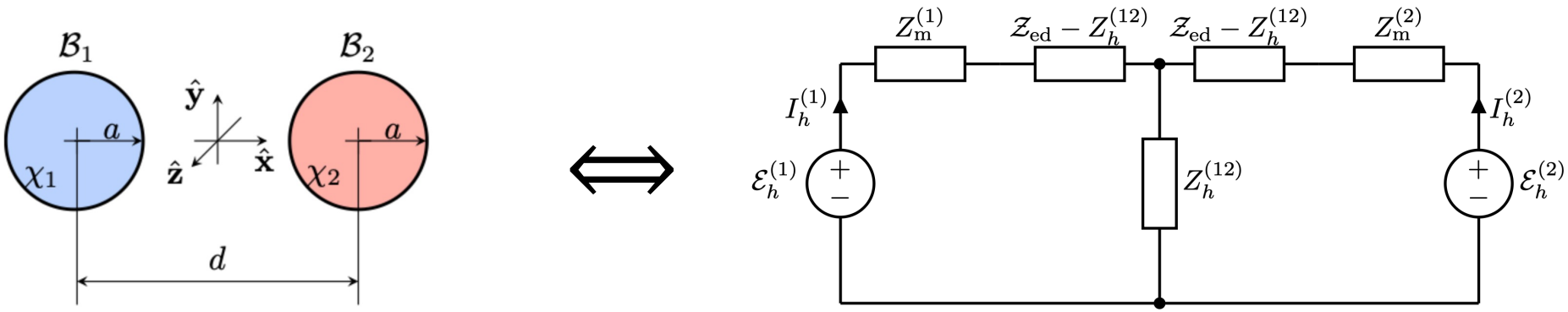
- **Why Exceptional?** **Square-Root splitting** (Puiseux series expansion) instead of linear (Taylor Series expansion) in the vicinity of θ_{ep}

$$\lambda(\vartheta) = \lambda_{\mathrm{ep}} \pm jb\sqrt{\delta\vartheta} + \mathcal{O}(\delta\vartheta)$$

- **Why Degeneracy?** At $\theta = \theta_{\mathrm{ep}}$ the operator $\mathcal{H}$ is not diagonalizable and the eigenbasis loss completeness (the eigenvectors are linearly dependent)

Research results

Exceptional Points in the Scattering Resonances of a Sphere Dimer



- We investigate EPDs in electromagnetic scattering of a **sphere dimer** from the electroquasistatic limit to the fully retarded regime.
- We derive an **equivalent circuit model** which is formally equivalent to the Coupled Dipole Approximations (CDA).

Research results

Exceptional Points in the Scattering Resonances of a Sphere Dimer

- We show that single-parameter perturbations yield the characteristic **square-root splitting** of the eigenvalues [Fig 1]
- We quantify its impact on scattering, extinction, and absorption, clarifying **sensing implications** [Fig 2].

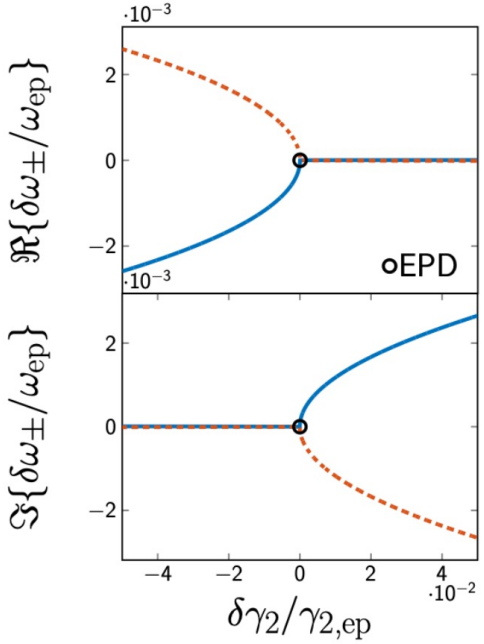


Fig. 1: Normalized Eigenfrequencies of the dimer as a function of the damping ratio

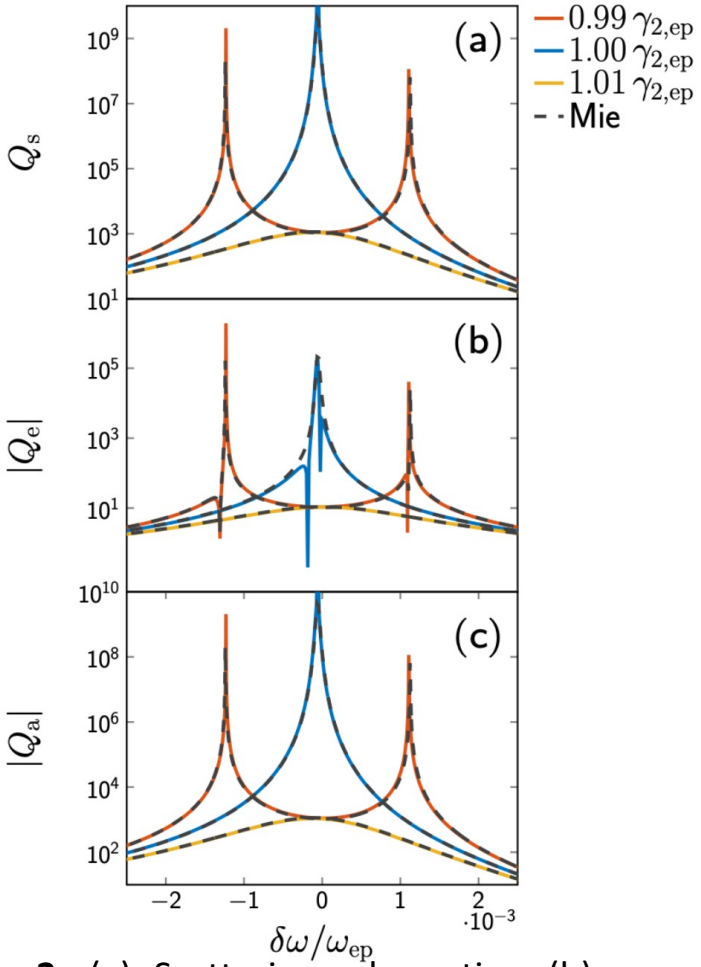


Fig. 2: (a) Scattering, absorption (b), and extinction (c) efficiency spectrum for three different value of the damping ratio

Research products

Published Journal Papers:

[P1]	**E. Corsaro**, G. Miano, A. Tamburrino, S. Ventre and C. Forestiere *Multilevel Fast Multipole Algorithm for Electromagnetic Scattering by Large Metasurfaces using Static Mode Representation,* in **IEEE Transactions on Antennas and Propagation**, (2025)

Papers in preparation:

[P2]	**E. Corsaro**, M. Balato, G. Miano, C. Petrarca, A. Alù and C. Forestiere *Mie Scattering Analog Circuit Emulator,*
[P3]	**E. Corsaro** et al. *Exceptional Points in the Scattering Resonances of a Sphere Dimer*

Next Year

- **Doctoral Research**: Investigating Extreme wave phenomena in linear and non-linear scattering

- **Methodology**: **Equivalent circuit** models as the fundamental approach

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