2023

Simons Collaboration

Satellite Workshop

ASRC Auditorium
85 St. Nicholas Terrace
New York, NY 10031

October 18

ADVANCED SCIENCE
RESEARCH CENTER
THE GRADUATE CENTER
CITY UNIVERSITY OF NEW YORK

Meeting Agenda

All talks are held in the ASRC Auditorium, 85 St Nicholas Terrace
Breaks are in the Café (adjacent to the auditorium)

8:30 a.m.	**Shanhui Fan**, ‘Scattering Matrix: Reciprocity Constraint, Unitary Control, And Topological Analysis’
9:00 a.m.	**Steven M. Anlage**, ‘Using Metasurfaces to Manipulate Complex Time Delay and Uncover Singularities in Wave Chaotic Scattering Systems’
9:30 a.m.	**Filiberto Bilotti**, 'The Role of Intelligent Metasurfaces in Future Smart Radio Environment'
10:00 a.m.	**Coffee Break**
10:30 a.m.	**Anthony Grbic,** ‘Space-Time Periodic Metastructures’
11:00 a.m.	**Femius Koenderink**, ‘Extreme Light Confinement In High-Q Systems, with Applications to Sideband-Resolved Molecular Optomechanics’
11:30 a.m.	**Francesco Monticone,** 'Physical Bounds And Extreme Effects in Electromagnetics Based on Temporal (a)symmetries'
12:00 p.m.	**Lunch Break - Cafe | Poster Session**
1:30 p.m.	**David Miller**, ‘Waves, Modes, and Minimum Thicknesses for Optics’
2:00 p.m.	**Mark Brongersma**, ‘Light Manipulation with Atomically Thin Quantum Metasurfaces’
2:30 p.m.	**Ben Z. Steinberg**, 'Non-Inertial Electrodynamics: Rotation, Symmetries, And Fundamental Solutions’
3:00 p.m.	**Jon Schuller,** 'Engineering Beam Symmetries for Optimized Multipolar Light-Matter Interactions’
3:30 p.m.	**Coffee Break**
4:00 p.m.	**Tingyi Gu,** ‘Chirality Control and Modulation in Integrated Photonic Resonators’
4:30 p.m.	**Ronny Thomale,** ‘Hyperbolic Wave Propagation in Electric Circuit Networks’
5:00 p.m.	**Romaine Fleury,** ‘Moving Objects in a Scattering Medium: A Wave Momentum Shaping Approach’
5:30 p.m.	**Closing Remarks**

Speaker Abstracts

Scattering Matrix: Reciprocity Constraint, Unitary control, and Topological Analysis

Shanhui Fan | Department of Electrical Engineering | Stanford University

We discuss some of our recent efforts in seeking to advance the mathematical studies of the properties of scattering matrix. Specifically, we introduce a reciprocity constraint on reflection. We also discuss the concept of unitary control for optical absorption and emission, and show that the mathematics formalism of majorization underlies such control. Finally, we introduce a theory on the topological properties of singular vectors and singular values of scattering matrices, and highlight the topological nature of the effects of coherent perfect absorption and coherent perfect extinction.

Using Metasurfaces to Manipulate Complex Time Delay and Uncover Singularities in Wave Chaotic Scattering Systems

Steven M. Anlage | Physics Department | University of Maryland

We identify the poles and zeros of the scattering matrix of a simple quantum graph by means of systematic measurement and analysis of Wigner, transmission, and reflection complex time delays. We examine the ring graph because it displays both shape and Feshbach resonances, the latter of which arises from an embedded eigenstate on the real frequency axis. Our analysis provides a unified understanding of the scattering properties of this simple graph on the basis of the distribution of poles and zeros of the scattering matrix in the complex frequency plane. It also provides a first-principles understanding of sharp resonant scattering features and associated large time delay in a variety of practical devices, including photonic microring resonators, microwave ring resonators, and mesoscopic ring-shaped conductor devices. Our analysis involves use of the reflection time difference, as well as a comprehensive use of complex time delay, to analyze experimental scattering data. We apply this to the study of an Aharonov-Bohm ring graph that is predicted to show asymmetric transmission in mesoscopic quantum samples that suffer from partial de-phasing. We then extend the use of complex time delay to understand the properties of a wave chaotic billiard that is perturbed by a wall-mounted tunable metasurface. The metasurface has sub-wavelength mushroom-shaped resonant elements whose reflection coefficient can be tuned significantly by applying a DC voltage to varactor diodes embedded in the surface. We find that tuning the metasurface is very effective at moving the poles and zeros of the billiard scattering matrix, and creates an abundance of coherent perfect absorption (CPA) and exceptional point (EP) events in the billiard. This, in turn, creates many opportunities for engineering unique scattering scenarios in a broad range of scattering systems.

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The Role of Intelligent Metasurfaces in Future Smart Radio Environment

Filiberto Bilotti | Department of Industrial, Electronic, and Mechanical Engineering | ROMA TRE University

The third generation of metasurfaces (i.e. metasurfaces whose properties can be controlled in space and time) is widely recognized as the key enabling technology for future wireless systems based on the smart radio environment concept. In particular, intelligent metasurfaces are used as reflective intelligent surfaces (RIS) for anomalous routing electromagnetic radiation and combined with regular antennas to enhance their properties.
In this scenario, the talk will focus on three main aspects:

I. **Real-life RIS implementation**

1. statistical analytical models describing the unpredictable effects due to fabrication tolerances, physical discontinuities, presence of bumps, overlooked mutual coupling among the unit-cells,
2. design strategies to develop smart biasing unit-cell grouping based on the complex vortex theory;

II. **Metasurface-aided signal processing**

1. design of time-modulated metasurfaces to perform analog signal manipulation at electromagnetic frequencies and at the speed of light, including Doppler shift compensation, false target creation, direction of arrival estimation, metasurface beamforming;

III. **A new generation of smart antennas – whose intelligence is enabled by the physical layer and not by signal processing modules - based on the combination of intelligent metasurfaces and regular antennas:**

1. single monopole/dipole radiators surrounded by cylindrical Huygens metasurfaces integrating communication and sensing capabilities and able to self-adjust operation frequency, radiation pattern, polarization state, visibility/invisibility,
2. antenna arrays covered by planar and dome-like Huygens metasurfaces characterized by enhanced scanning properties, reduced insertion loss, spatial filtering operation.

Spatially-Discrete, Traveling-Wave Modulated Metastructures

Anthony Grbic | Department of Electrical Engineering and Computer Science | University of Michigan

Periodic boundary conditions are indispensable in the design of spatially periodic electromagnetic structures such as phased array antennas, photonic crystals and metamaterials/metasurfaces. In this talk, an analogous boundary condition will be presented for space-time periodic structures that are spatially-discrete, traveling-wave modulated (SDTWM). In these structures, a spatial modulation period consists of N unit cells, referred to as stixels (space-time pixels). The modulation of each stixel is staggered in time by a time interval equal to 1/N of the temporal modulation period (T). Such a modulation scheme establishes a space-time periodic boundary condition, referred to as the interpath relation, across each stixel. This boundary condition can be viewed as a frequency (harmonic) dependent Bloch condition.
In this presentation, the Interpath Relation will be reviewed and intuitively explained in both time and frequency domains. It will be used to understand and efficiently compute the response of SDTWM metastructures and circuits. The Interpath Relation will also be used to show how both band structure and space-time modulation can be engineered to tailor spatial and temporal spectra.

Extreme Light Confinement in High-Q Systems, with Applications to Sideband-Resolved Molecular Optomechanics’

Femius Koenderink | AMOLF Institute | Center for Nanophotonics

A longstanding quest of nanophotonics is to reach extreme values of the local density of optical states (LDOS) by means of tightly confined and long-lived resonances. While for spontaneous emission control one generally simply desires the highest LDOS value at a single location and frequency (that of the emitter), in other scenarios texturing the LDOS in space, vector nature, or spectrum is of high interest. For instance, the recently emerging field of molecular optomechanics targets extreme interaction of light and molecular vibrations, enabling for instance parametric driving and cooling of molecular motion, or coherent frequency upconversion from visible to infrared light, mediated by vibrations. In such a context there is a large interest in shaping the LDOS in frequency to, e.g., selectively promote Stokes scattering, yet suppress anti-Stokes scattering, or vice versa. At the same time it is clear that such LDOS control is constrained by fundamental limits, for instance in the generally accepted tradeoff between spatial confinement (championed by plasmonics) and temporal confinement (championed by microcavities). We are interested in pushing these fundamental limits, using hybrid plasmonic-photonic resonators as a basic motif. I will discuss the physics and realization of a variety of such hybrid plasmonic-photonic resonator realizations.

Physical Bounds and Extreme Effects in Electromagnetics Based on Temporal (a)symmetries’

Francesco Monticone | School of Electrical and Computer Engineering | Cornell University

Temporal symmetries (time-reversal and time-translation) and asymmetries (the one-sided nature of the temporal impulse response, i.e., causality) play a crucial role in the response of natural and engineered materials and in the general behavior of wave physics phenomena. In this talk, I will discuss our recent efforts on probing fundamental limitations and extreme effects in electromagnetics and photonics based on these concepts.

Waves, Modes, and Minimum Thicknesses for Optics’

David Miller | Department of Electrical Engineering | Stanford University

Based just on the mathematical function some optics is to perform, we deduce a minimum thickness of any optical approach, including metasurfaces. This thickness is derived based on a “communication mode” understanding of waves between input and output surfaces. It arises if the input regions for different output “pixels” overlap, leading to a “overlapping nonlocality” number C that, combined with diffraction heuristics, gives this limit.

Light Manipulation with Atomically Thin Quantum Metasurfaces

Mark Brongersma | Geballe Laboratory for Advanced Materials | Stanford University

In the field of optics, we are used to direct light waves with bulky optical components. The development of metasurfaces has recently brought many exciting new ways to manipulate the flow of light. These are essentially flat optical elements comprised of a dense arrays of nanostructures that can scatter light and thereby impart space-varying phases on an incident light wave.

The ultimate physical limitations of these optical components can be traced back to the properties of the materials and building blocks that they are constructed from.Current metasurface designs largely employ metallic or high-index nanostructures. They afford strong scattering because of their plasmonic and Mie resonances that enable them to serve as optical antennas. However, emerging metasurface applications in quantum optical communications, augmented reality, non-linear optics, and spatiotemporal light control demand much more than the basic, linear, and typically-static scattering responses provided by such geometrically-shaped antennas. In this presentation I will ask the question whether the unique quantum properties of atomically-thin quantum can be harnessed to create atomically-thin vdW metasurfaces with radically new functionalities.

Non-Inertial Electrodynamics: Rotation, Symmetries, and Fundamental Solutions

Ben Z. Steinberg | School of Electrical Engineering | Tel-Aviv University

The electrodynamics (ED) of moving, accelerating or rotating structures and metamaterials supports unique effects of light-matter interaction such as dynamically controlled bi-anisotropy and non-reciprocity, vacuum-friction, and gain and instabilities. These may potentially serve as platforms for new technologies and applications such as isolators and circulators, energy harvesting devices, rotation sensors and more. Of particular interest is the case of structures rotating at a given angular velocity , as rotation is inherently non-inertial and exhibits a wide class of unique physical phenomena. Furthermore, compare to linear translation, rotation can be manifested in smaller physical settings.

The ED of rotating structures as observed in the laboratory (inertial) frame of reference has been investigated extensively. These studies are usually restricted to simple geometries and structures that possesses a high degree of symmetry (e.g. bodies of revolution, rotating around their own symmetry axis) and consisting of a single scatterer. This limitation is mainly due to the difficulty associated with time-varying complex geometries and surfaces.

Here, we explore the fundamental electrodynamic properties of rigidly rotating structures as observed in the structures' rest frame of reference . This approach alleviates the difficulty pointed above. It also exposes new physical phenomena and symmetry properties associated with scattering from rotating complex structures, and opens the way to a new class of applications. We discuss these symmetry properties associated with a single scatterer as well as with particle arrays, fundamental solutions and Green's functions in , and their potential applications.

Engineering Beam Symmetries for Optimized Multipolar Light-Matter Interactions

John Schuller | Department of Electrical Engineering | Stanford University

When engineering extreme light-matter interactions, scientists typically focus on engineering matter. Here, I describe methods for optimizing multipolar light-matter interactions by engineering light symmetries. I conclude by detailing recent experiments where we use these methods to demonstrate the only known example of a material with atomic-scale non-unity optical frequency magnetic permeability.

Chirality Control and Modulation in Integrated Photonic Resonators

Tingyi Gu | Department of Electrical and Computer Engineering | University of Delaware

Non-Hermitian systems with their spectral degeneracies known as exceptional points (EPs) have been explored in micro-resonators by introducing two or more nanotips into the resonator's mode volume. While this method provides a route to study EP physics, the basic understanding of how the nanotips' shape and size symmetry impact the system's non-Hermicity is missing, along with additional loss from both in-plane and out-of-plane scattering. Here we use lithographically defined asymmetric and symmetric Mie scatterers, which enable subwavelength control of wave transmission and reflections without deflecting to additional radiation channels. We show that those pre-defined Mie scatterers can bring the system to an EP with the feasibility of dynamic modulation, as well as enable chiral light transport within the resonator. The Mie scatterer results in an enhanced quality factor measured on the transmission port, through coherently suppressing the backscattering from the waveguide surface roughness. The mechanically stable laser-cavity detuning enables the route of using EP effects for switching and modulation.

References

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Hyperbolic Wave Propagation in Electric Circuit Networks

Ronny Thomale | Department of Theoretical Physics I | University of Wuerzburg

Electric circuits allow to realize a network connectivity related to Poincare-projected (2+1) hyperbolic space. Creating a voltage wave package and studying its propagation, we observe the horocycle wavefront behaviour in hyperbolic space and discuss the impact of different lattice tesselations. We outline several directions of future research such as realizing hyperbolic anti-de Sitter space in circuits and, from there, creating a black hole embedded in hyperbolic space which might allow us to study AdS/CFT correspondence in a tabletop experiment

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Moving Objects in a Scattering Medium: A Wave Momentum Shaping Approach

Romain Fleury | Laboratory of Wave Engineering | EPFL

In scattering media, such as biological tissues, focusing electromagnetic or acoustic wave energy at a desired location is extremely challenging. The same is true for momentum: using waves to move or rotate small scatterers remains largely elusive. The difficulty is not only to send the right wavefronts, but also to update them correctly as the object moves. In this talk, I will discuss how general energy conservation rules can be leveraged to guide or rotate objects in a scattering medium, using a wave momentum shaping approach that only uses far-field measurements. A proof of concept experiment with sound validates the method for translations and rotations in both static and time-dependent disordered environements.