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Branched Flow of Light

RESEARCHERS

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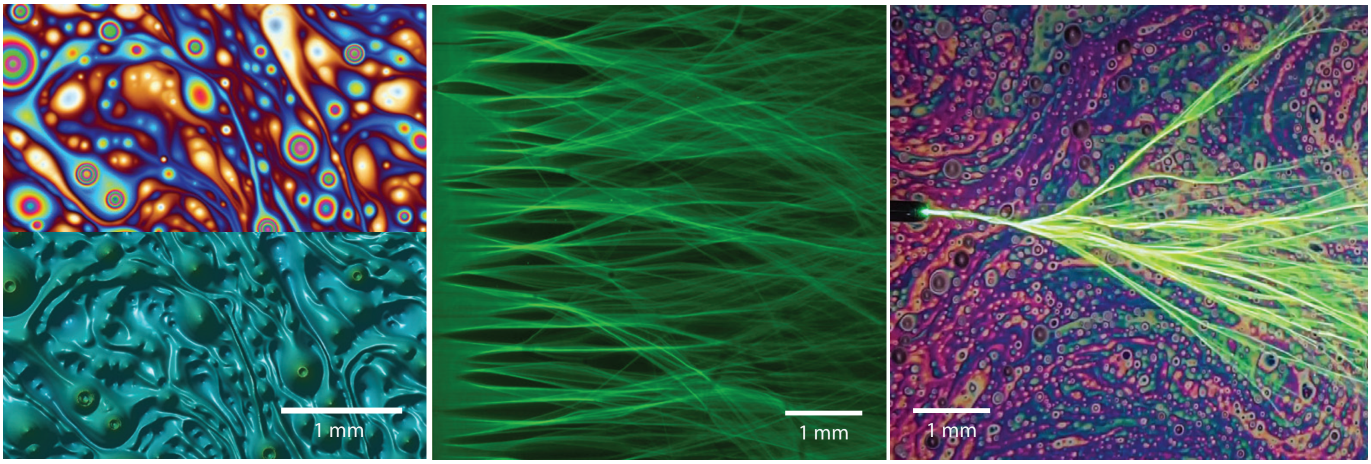
Branched flow is a universal wave phenomenon in which waves form channels of enhanced intensity that keep dividing as they propagate, resulting in a beautiful pattern resembling the branches of a tree. It occurs when waves propagate in a smooth, disordered potential, with a correlation length longer than the wavelength.

Branched flow essentially constitutes an intermediate regime between ballistic propagation and diffusive transport in highly scattering media. First observed for electrons,[1] branched flow can occur for virtually any kind of wave. It has been observed in microwave cavities,[2] for example, and has been proposed as a focusing mechanism of tsunami waves.[3]

Recently, we presented the experimental observation of branched flow of light.[4] Our scheme relies on a laser beam propagating inside a thin liquid film—a soap membrane. The membrane acts as two-dimensional (slab) waveguide that, in our parameter regime, supports a single guided mode. The local thickness variations of the membrane lead to substantial variations of the effective index of refraction. To observe branched flow, we manipulated the soap film to create disorder landscapes of smooth thickness variations, to form a disordered correlated potential.

From these experiments, we have extracted the statistical properties of branched flow. By launching a plane wave into the disordered membrane, we demonstrated that the mean distance to the first branch matches the predicted position calculated using the measured correlation length and strength of the potential, obeying a universal relation. Further, by using narrow-beam excitations, we observed that the statistics of the branch intensities display a heavy-tail probability distribution due to the correlations in the potential. Finally, we found that these branches are highly non-diffracting, staying focused for distances much larger than the diffraction length of beams of the same width in homogeneous media.

Bringing branched flow to optics opens the door to a wealth of new ideas, such as branched flow in nonlinear media, in curved space or in systems with gain and loss. The labile nature of soap films and the highly intense branches bring about a new regime in which branched flow of light may trigger extreme nonlinear phenomena[5] or interact and affect the disorder through radiation pressure and the gradient force. OPN



Top left: True-color interference of white light reflected from soap membrane. Bottom left: Reconstruction of membrane thickness, which maps to a refractive-index landscape. Center: Observed branched flow of light for a plane wave. Right: Observed branched flow of light when a narrow beam is launched into the membrane, forming narrow, high-intensity branches that remain focused for large distances in the disordered medium.

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