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The dating game at dimension zero: creation and annihilation of phase singularities in optical random waves

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Abstract: Phase singularities can be created and annihilated, but always in pairs. With optical near-field measurements, we track singularities in random waves as a function of wavelength, and discover correlations between creation and annihilation events.

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Phase singularities are locations in which the phase of a complex field is undefined. In two dimensions these deep-subwavelength (size zero) optical entities are points in the plane around which light's phase swirls, with positive or negative topological charge, depending on the swirling direction [1]. In a monochromatic field of random waves phase singularities are frozen in time, with a spatial distribution reminiscent of that of particles in a simple liquid, and strictly related to the wavelength of the field [2, 3]. Only when this wavelength is finely tuned singularities start to move, exhibiting the Brownian statistics of a random walk [4].

Unlike particles in a simple liquid, their size zero enables phase singularities to be at the same location, fact which can indeed be inferred for singularities in a random wave field [2, 3]. In this relevant case, when two singularities share the same location they always have opposite topological charge, resulting in their mutual annihilation. New pairs can be created as well. With near-field experiments we track phase singularities at varying the wavelength of optical random waves. Figure 1 presents an overview of such near-field measurements, highlighting the creation and

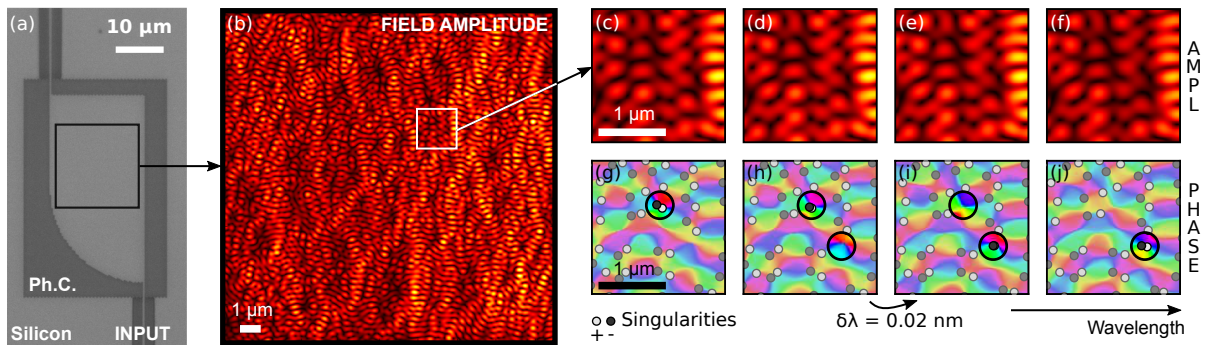


Fig. 1. Overview of the near-field measurements for the detection and tracking of phase singularities in random waves. (a) The chaotic cavity: a silicon on insulator photonic crystal cavity. Light is coupled in from the input waveguide, and then confined in the cavity, the shape of which is engineered to allow the mechanism of wave chaos [5]. (b) Typical mapping of the amplitude of one Cartesian component of the optical field inside the cavity. (c-j) Subsections of the full mappings measured at varying input wavelength in the telecom region, for amplitude (c-f) and phase (g-j) of the optical field. Phase singularities are represented by gray circles. Creation and annihilation of singularities pairs are highlighted with black circles.

annihilation of pairs of singularities (black circles in Fig. 1h-i).

Our full mapping of the singularities trajectories from *birth* to *death* enables us to elaborate on such creation and annihilation events. We discover that the typical persistence of singularities in the random field goes hand in hand with their lifelong fidelity [6], i.e., the correspondence between creation and annihilation partner of a singularity (Fig. 2a). Finally, we relate persistence and fidelity of singularities to the correlation properties of the optical random field in which such entities arise, seeking for an explanation for the differentiation between *faithful short-living* and *unfaithful long-living* singularities, as suggested by our experiments. We support our measurements with finite element method (FEM) simulations (Fig. 2b) as well as with simple modeling (gray lines in Fig. 2), partially validating our experimental results. Besides, computational modeling allows us to definitively exclude a whole series of experimental artifacts one could think of, strengthening our experimental observation of an outstanding *short-living* population of *faithful* singularities arising in the optical random field. We propose a mechanism that could explain the existence of such *short-living* component, laying down the foundations for further theoretical understanding.

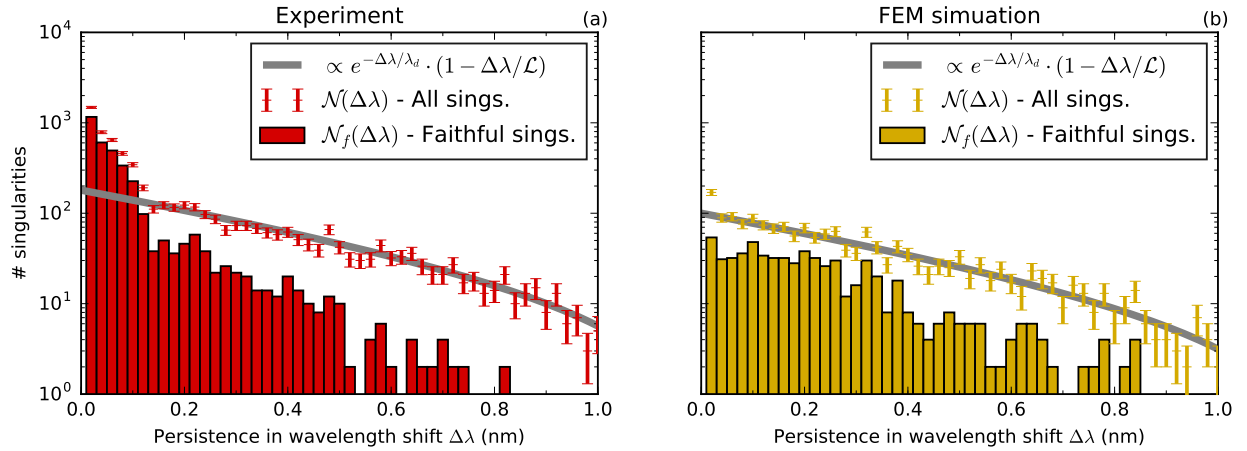


Fig. 2. Number of singularities \mathcal{N} persisting in the optical random field for a given wavelength shift $\Delta\lambda$ (dashes). The boxes are the same type of persistence histogram, but only for the *faithful* singularities (\mathcal{N}_f). The gray line is the expected behavior for $\mathcal{N}(\Delta\lambda)$, obtained with a simple model of the wavelength-dependent random field. (a) Results from near-field measurements. (b) Results from finite Element Method simulation.

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