

# Inelastic scattering puts in question recent claims of Anderson localization of light

**To the Editor** — In a recent Letter in *Nature Photonics*, Sperling *et al.*<sup>1</sup> reported the observation of Anderson localization of light in three dimensions. In contrast to previous studies, the authors designed their experiment to be insensitive to absorption. To this end, they measured the time-dependent broadening of a high-intensity, short laser pulse transmitted through a highly scattering medium made from compressed TiO<sub>2</sub> powder. In analogy with the case of disordered optical fibres<sup>2</sup>, localized light is expected to be laterally confined to roughly the localization length  $\xi$ . Using an ultrafast imaging system, Sperling *et al.* experimentally observed the saturation of the time-dependent transverse width of the total transmitted light intensity, and from this, they derived the claim for the first unequivocal observation of the three-dimensional localization of light.

In this correspondence, we would like to point out that the Letter of Sperling *et al.* does not report on the observation of elastic scattering of light waves, which is considered to be a necessary condition for the occurrence of Anderson localization. In his recent PhD thesis<sup>3</sup>, Wolfgang Bührer (who was supervised by Maret and Aegerter) reported that highly nonlinear contributions exceed the linear (elastic) scattering signal by at least one order of magnitude in the most relevant regime, namely the long-time regime ( $\tau/\tau_{\max} \approx 3$  in Fig. 2 of ref. 1). Although such

incoherent light makes an extremely small contribution to the total transmission, it becomes the dominant contribution to the late arriving signal once the elastically scattered light has leaked out of the sample. Wavelength-resolved experiments reported in this thesis on samples similar or identical to the ones studied in ref. 1, show that the non-exponential tail of the transmitted pulse disappears when the spectrally shifted contributions are blocked by a band-pass filter.

We believe that the dominant contribution of incoherent light puts in question not only the recent claims by Sperling *et al.* but also similar claims of localization by the same group in 2006 based on time-resolved measurements alone<sup>4</sup>. The long-time regime lies at the heart of both claims of localization, as this is the regime in which the saturation of the transverse width was observed in ref. 1 and in which the deviation from non-exponential decay was observed in ref. 4. Although Bührer extensively studied this incoherent contribution previously<sup>3</sup>, it was not mentioned in ref. 1.

We note that it is relatively easy to confuse nonlinear effects with localization in this type of experiment using pulsed laser sources. For example, photons generated by nonlinear processes (such as radiative decay after two-photon absorption) are emitted with a distribution of time delays  $\Delta t$ , which contribute to a narrower transmission profile

$$T(\rho, t) = T_{\text{elastic}}(\rho, t) + T_{\text{inelastic}}(\rho, t - \Delta t)$$

at the output. The transition from elastic to inelastic scattering in the long-time regime can thus result in an ‘apparent’ saturation of the transverse width, resembling that of localization. Also, the different particle sizes and the different pressures used to produce samples of varying packing fractions can lead to differences in nonlinear optical coefficients, which can be easily misinterpreted as a localization effect that depends on the scattering strength ( $kl^*$ ), whereas it is actually a nonlinear optical effect. □

## References

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2. Segev, M., Silberberg, Y. & Christodoulides, D. N. Anderson localization of light. *Nature Photon.* **7**, 197–204 (2013).
3. Bührer, W. *Anderson Localization of Light in the Presence of Nonlinear Effects* PhD thesis, Univ. Konstanz (2012).
4. Störzer, M., Gross, P., Aegerter, C. M. & Maret, G. Observation of the critical regime near Anderson localization of light. *Phys. Rev. Lett.* **96**, 063904 (2006).

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**Maret *et al.* reply:** The interplay between nonlinear effects and Anderson localization in disordered optical fibres<sup>1</sup> has recently attracted great interest, and it is important in the action of random lasers in which closed multiple scattering loops have enhanced intensity<sup>2</sup>. As optical nonlinearities in TiO<sub>2</sub> can give valuable information on the nature of light transport in strongly scattering powders, we studied these effects in an extended experimental and theoretical investigation (to be published). Now, Scheffold and Wiersma have put forward that such effects may question the interpretation of the results of our recent experiments in terms of Anderson localization<sup>3,4</sup>.

As noted by Scheffold and Wiersma, our measurements of the time-dependent transmission profiles<sup>4</sup> eliminate the influence of absorption. This technique thus reveals the signatures of Anderson localization more clearly than integrated transmission data<sup>3</sup>. The relevant signals appear at different timescales, which is also true for the nonlinear contributions in our study to be published. Based on the arguments put forth by Scheffold and Wiersma, one would expect that no saturation of the profile would be observed when a band-pass filter for the incoming wavelength is inserted. However, such an experiment (Fig. 1) clearly shows

saturation of the profile width, similar to that reported in ref. 4, irrespective of the detected frequency.

In addition, we emphasize that the dependence of the localization length on  $kl^*$  was determined in two separate ways in ref. 4. Besides the variation of the samples and the packing fractions mentioned by Scheffold and Wiersma, we also investigated the change in the scattering strength induced by varying the incident wavelength. Our data presented in two different studies<sup>3,4</sup>, exhibit a remarkable scaling with the turbidity measured by  $kl^*$  — exactly as expected for three-dimensional Anderson localization.