transition between two electronic states of the cation.

Chiral HHG detection is a novel approach to chiroptical spectroscopy, capable of characterizing molecular chirality on femtosecond timescales[4]. Chiroptical spectroscopy relies on a difference between the response of left-handed and right-handed molecules to light, which in this case is observed in the HHG-maximizing ellipticity, which has opposite sign for the different chiralities. Furthermore, the absolute value of the HHG-maximizing ellipticity at a certain harmonic order (proportional to the emitted photon energy) reflects electronic chiral dynamics. Such sub-femtosecond dynamics carry information on the density and population evolution of electronically excited states of the molecular cation transiently generated during the HHG process. Indeed, the HHG yield spectrum resulting from chiral response gives surprising insight into the chemical structure and proximal functional groups around each chiral centre.

The success of the chiral HHG method as a chiroptical characterization tool relies on the efficiency and preciseness of the nonlinear frequency conversion process that is induced by an intense infrared pulse. But the HHG yield and specificity can be reduced by a number of factors, such as a capturing of liberated electrons by nearby chemical groups within the chiral molecule and the existence of multiple chiral centres in complicated natural products and biological molecules. Therefore, a strong and tunable infrared laser, combined with selection schemes for site-specific (multiphoton) excitations, needs to be developed. With such improvements, the enantiomer-sensitive method of chiral HHG could open a new and unexplored forefront for chiroptically controlling electrons that are involved in fundamental chemical and biological processes. ❐

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MULTIPLE SCATTERING

Unravelling the tangle

The discovery of a new correlation between the incident field and the laser speckle created by multiple scattering takes us a step closer to imaging in turbid media.

Jacopo Bertolotti

A strongly scattering material can be considered a barrier for information. Even if a turbid medium allows some of the light incident on it to be transmitted, the wavefront is scrambled and forms a speckle pattern — and precious little information about what was on the other side survives the process. If we happen to be able to fully characterize the barrier we can computationally reverse the scattering process and recover a perfect image[1], but if we do not, we need to distil as much information as we can from the scattered light. Writing in *Nature Physics*, Benjamin Judkewitz and co-workers[2] report the discovery of a new correlation between the incident and scattered light, describing how a part of the original information manages to survive the scattering process.

Optics was one of the first sciences to be developed, with primitive lenses dating back as far as 750 BC (ref. 3). From the earliest magnifying lenses to modern microscopes and telescopes, the idea behind any imaging system remained basically the same: collect the light scattered or emitted by an object and reform an image over a detector, where it can be recorded. In almost 3,000 years an enormous number of such systems have been developed, each sparking its own scientific revolution, from the Galilean telescope that gave rise to modern astronomy, to the optical microscope that made microbiology possible. In more recent years, as our understanding of electrodynamics became more and more complete, scientists began to challenge the traditional schemes and started to pay more attention to the role of prior information in imaging. This change of perspective led to microscopy techniques, among others, that allowed the diffraction limit to be broken[4].

When uncontrolled disorder is present, any imaging system based on a deterministic description of light propagation shows a loss of resolution and/or contrast in the final image.

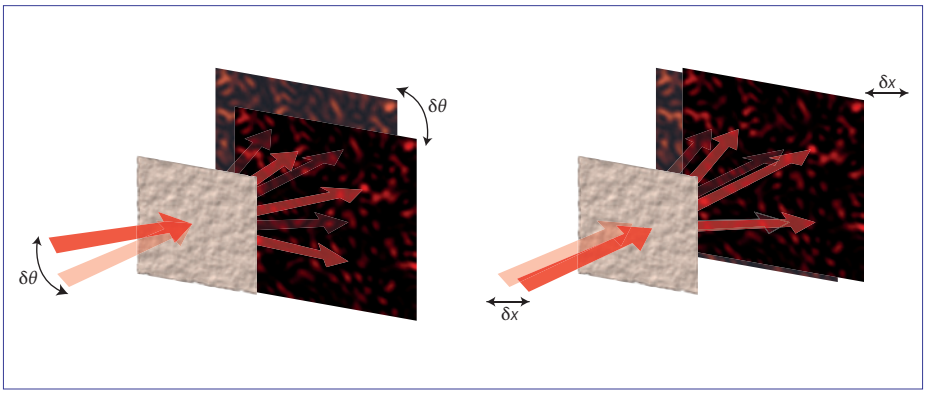

Figure 1 | The optical memory effect. Due to the optical memory effect, if we tilt the incident laser by a small angle, $\delta\theta$, the speckle pattern produced by the interference of multiply scattered light on the other side of the turbid layer will tilt by the same angle (left panel). Judkewitz and colleagues[2] demonstrate that a similar effect occurs when the incident beam is not tilted, but shifted by a small amount δx (right panel).

Often, laboratory conditions are sufficient to provide a scatter-free environment, sometimes it is possible to remove the unwanted scattering by optical clearing[5] and at times the measurement can be restricted to collect only the light that was unscattered by the disorder[6]. But sometimes scattering is either unavoidable or an integral part of the object we want to study. In such cases we have to accept that most of the approaches we are familiar with are not going to work and we need to look at the problem from a different perspective.

Knowing the full scattering matrix that describes the disorder would allow us to make sense of the scrambled signals we measure[1], but for most realistic systems such matrices can easily have billions of elements, making a complete characterization extremely difficult at best. Luckily, even a partial knowledge of this matrix is often enough to focus light through a strongly scattering layer or even transmit images through it[7]. The presence of correlations in the scattered light helps enormously in this process, as it means that the elements of the scattering matrix are not fully independent, and thus we can infer part of the matrix from a limited number of measurements. The simplest and most used of such correlations is known as the optical memory effect, which tells us that if we slightly tilt the beam incident on a turbid medium, the speckle pattern produced on the other side will simply tilt by the same angle[8] (Fig. 1). By increasing the tilting angle the speckle will continue shifting, but it will also start changing, and for an angle larger than the memory range we will lose any correlation with the original pattern. Thus, we can use our knowledge of the scattering matrix at one point to correct the image not only at that point, but also in a patch around it, for instance when employing adaptive optics.

Judkewitz *et al.*[2] realized that this tilt–tilt correlation must have a twin brother, a shift–shift correlation that links the speckle produced by a beam with the speckle produced by a shifted beam, which becomes manifest as soon as the scattering is anisotropic — when forward scattering is more probable than high-angle scattering. This extra hypothesis is not very limiting as most biological systems, where scattering and turbidity are a major problem for imaging, present a marked forward scattering. The basic idea is that, due to the anisotropy in the scattering process, the light emerging from the turbid medium will not be dispersed isotropically as it is in the diffusion approximation, but will retain a significant forward component, that is, the scattered light will retain some memory of the original direction of the beam. Because the speckle produced by the scattered light in the far-field is connected to the light emerging from the turbid medium by a Fourier transform, the angular memory due to the anisotropy is transformed in a correlation between the patterns produced by shifted beams.

Although this new correlation is yet to be demonstrated in a working imaging system, we have reasons to be optimistic. In fact, this correlation is complementary to and concurrent with the optical memory effect, suggesting that all the systems currently exploiting the latter can also take immediate advantage of the former. Furthermore, the authors argue that, unlike the optical memory effect, this new correlation should also hold inside a scattering medium, and not only at a distance from it. This would open up the possibility of using the approach to develop novel imaging techniques capable of resolving objects buried deep inside strongly scattering biological tissue. ❐

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SUPERNOVAE

Turning off the lights

Decades-long repeat observations of supernova 1987A offer us unique, real-time insights into the violent death of a massive star and its long-term environmental effects, until its eventual switch-off.

Richard de Grijs

On 23 February 1987, SN1987A — the explosive last gasps of a dying massive star — suddenly illuminated the Large Magellanic Cloud. Such bright stellar explosions occur only once or twice per century in large spiral galaxies like our Milky Way and much less frequently in Magellanic-type 'dwarf' galaxies. At a distance of 163,000 light years[1], SN1987A was the closest recorded supernova since Kepler's Supernova in 1604 and Cassiopeia A in the late 17th century, both of which occurred in the Milky Way. Fortunately, we now have access to cutting-edge astronomical facilities, thus allowing us to monitor the explosion and subsequent evolution of the entire SN1987A system in real time.

In a recent article in *The Astrophysical Journal Letters*, Fransson *et al.*[2] present a 20-year timeline of changes in the appearance of the supernova's complex system of rings (Fig. 1). Two of these rings are most likely caused by mass outflows from its red supergiant progenitor star up to 20,000 years before the explosion[3]. The brighter but smaller inner ring, on the other hand, was generated by interactions of the progenitor's swept-up stellar wind with the ambient gas. Hubble Space Telescope observations have enabled us to witness the appearance and subsequent disappearance of 'hot spots' along this latter circumstellar ring. These are likely caused by interactions of the densest gas clumps in the circumstellar gas with the supernova's outward-propagating blast wave, thus leading to the appearance of a ring-like shape. The expanding supernova debris left behind after the blast wave passed by is decelerated by a 'reverse shock', which is due to electrons cascading down to lower energy levels following collisional excitation of neutral hydrogen atoms, triggered when the debris crosses the shock front.