X-ray movies

Christian Günther explained to *Nature Photonics* that holography offers great promise for capturing X-ray movies on femtosecond timescales.

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Left to right: Bastian Pfau, Christian Günther and Stefan Eisebitt. Günther and colleagues have realized a technique that uses holography to obtain sequential X-ray images just femtoseconds apart, allowing many high-speed processes to be imaged at high resolution.

What is the driving force behind the current interest in X-ray optics?
One of the main driving forces is that the resolution of light-based microscopes is too limited for probing the nanoworld. In addition, X-rays offer some useful properties. For example, although electron imaging schemes can achieve the required resolution for probing nanoscale objects, X-rays can penetrate deeply and provide special contrast mechanisms. That's why people are motivated to build next-generation X-ray sources, even though they are huge facilities that cost a lot of money to build. Think back to what the laser did for optics; in some ways, people are expecting the same for X-rays. New X-ray sources will provide huge intensities and ultrashort timescales that were never previously accessible.

Why do we need X-ray movies?
Taking just one image usually provides only an initial or final state, but often you want to know what is happening in between — how a process, such as a reaction or some other dynamic phenomenon, takes place. For this you need a frame rate that is faster than the process being investigated. Pump–probe experiments, in which you pump with a laser and probe with an X-ray beam, often work nicely, but many processes cannot be imaged using this technique. It would therefore be nice to have a technique that takes a sequence of images — a movie — with a fast frame rate and at high resolution.

What is the difficulty in making X-ray movies?
The main challenge is achieving a suitable, ultrafast frame rate. We really want to observe processes in the femtosecond regime. Making an observation, capturing the required data and then repeating this process almost instantaneously is a tremendous challenge. In the femtosecond regime, information does not travel very far even at the speed of light — only a few micrometres. It is therefore difficult to extract the information out of the detector quickly enough, and this is where our approach helps.

How did you do it?
We used a holographic technique. In holography, scientists make use of one or more references, meaning that in a single shot you can form multiple independent images of the object. We realized that properly controlling the illumination allows the user to obtain images that not only are independent, but also that correspond to different points in time. This essentially allows the temporal information to be mapped to spatial information in the hologram. The beauty of this technique is that the time difference can be extremely short, even down to a few femtoseconds. Once the idea was born the experiment itself was comparatively easy to perform, although it did require the interplay of certain complex instruments, including the autocorrelator, the holography set-up and the X-ray laser itself. Another serious challenge was performing the experiments within the short timescale allotted by the X-ray source.

How many images does this technique provide?
We currently take just two closely spaced images. Two images is the minimum number required to obtain information about the evolution of the system, but more images would of course be nice to have. Our holographic principle does allow this, but the difficulty lies in splitting the initial pulse into many subsequent pulses. It can be done, but this process loses a lot of X-ray intensity per pulse. We split the pulse optically, but new concepts for producing multiple pulses by manipulation of the electron bunch in the X-ray laser are now emerging.

What factors limit the resolution?
In this experiment we focused on achieving high temporal resolution. Of course the duration of the X-ray pulse is a limiting factor. We got down to around 50 fs, but our method will also work with attosecond pulses. I wouldn't be surprised to see improvements in pulse duration of one or two orders of magnitude over the next decade, thanks to new next-generation X-ray sources. The spatial resolution is the greater challenge — wavelengths of around 10 nm are state-of-the-art in any type of X-ray imaging, and getting significantly beyond this will take great effort.

INTERVIEW BY DAVID PILE

Christian Günther and colleagues have a Letter on sequential X-ray imaging at femtosecond timescales on page 99 of this issue.