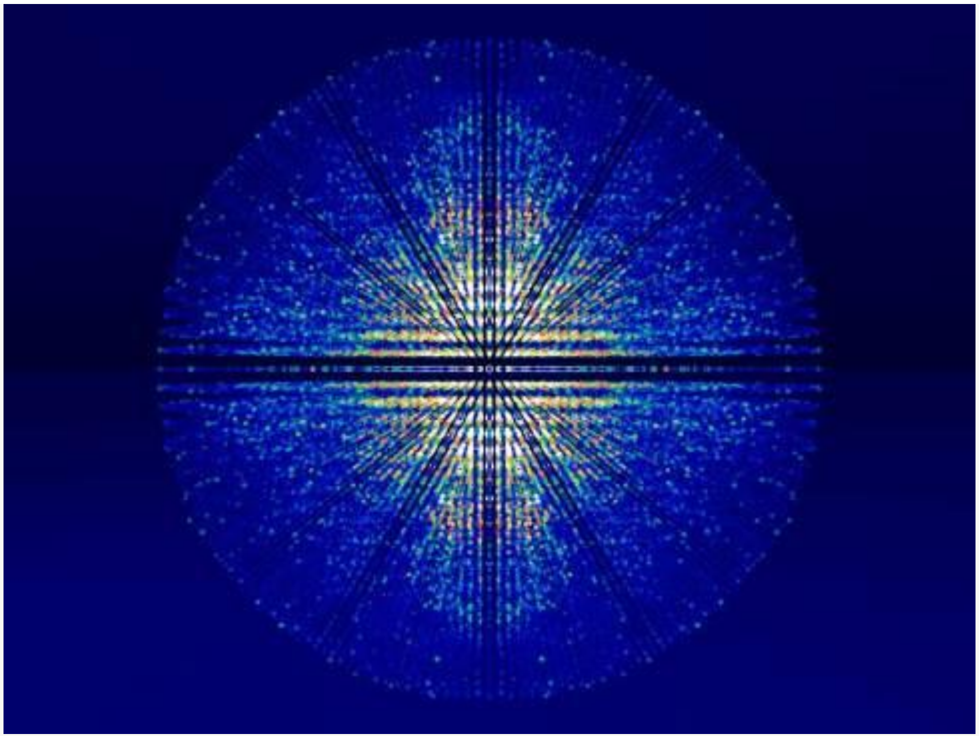
THE ULTIMATE X-RAY MACHINES ARE READY TO GO



X-ray data of protein crystals obtained from over 15,000 single snapshots. Credit: Thomas White, DESY

When you go to the doctor for an X-ray, the nurse or doctor briefly disappear behind a screen, presses a button for a brief moment, and you're all set. It seems an X-ray takes about a second but the actual exposure times is much faster. Milliseconds more likely.

Such speeds seem like almost an eternity compared to what is achieved by a new generation of X-ray sources that have begun to become operational: free-electron X-ray lasers. The first of these big machines is the LCLS at Stanford University, which achieves laser pulses shorter than 70 femtoseconds (100 femtoseconds = 1/10 of a trillionth of a second). The beam intensities of these lasers are ten billion times brighter than the sun. And all this with a potential imaging precision down to the atomic scale. In other words, if you like to take things to the extreme, these lasers are for you. In one of the first studies to make use of the LCLS X-ray free-electron laser, two research collaborations now present first experiments on biological samples in this week's *Nature*.

Imaging biological samples

Bones appear much stronger in X-ray scans than soft tissue. That's because X-rays don't interact so much with the carbon and hydrogen atoms of soft organic tissue, which makes it more difficult to measure with X-rays. And that's why these two *Nature*studies are so relevant. The first of these studies looked at a mimivirus, which with a size of 0.45 micrometers is the largest virus known. The aim was to take a picture of the virus' interior by measuring the diffraction of the X-rays by the virus. To image such a small object in this way the X-ray beam is highly focused, to a spot of about 10 micrometers in size. At the same time laser beam intensities are immense: the researchers calculate that a single laser pulse heats the sample by 100,000 K. But that doesn't really matter. Only one pulse passes through the sample and that is so short that the heating begins only after the X-rays have passed through. The viruses never know what hit them. The image of the virus taken with such a single shot has a resolution of about 32 nanometers, and does indeed show a somewhat softer virus interior.

The topic of the second paper also uses the diffraction of X-rays, but to measure the structure of a protein. To achieve optimum resolution, more than three million snapshots were taken. Of course, because of the high beam intensities the protein can't stay in the laser beam all this time. Rather, the crystals are flushed through the apparatus in a water jet. The resolution the researchers achieve this way is about 8.5 Angstrom, which is actually not better than what the competition, synchrotrons, can achieve. The benefit of these free electron lasers is, however, that the pulses are so short that the samples don't need to be cooled down. Room temperature is perfectly fine.

What are these free-electron lasers?

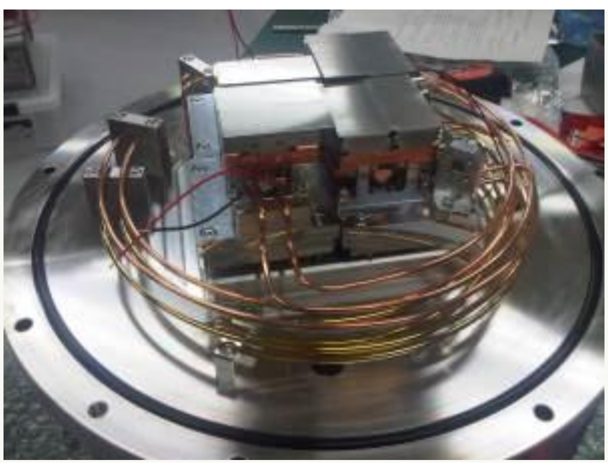
In an X-ray free electron laser the electrons are first accelerated to extreme velocities close to the speed of light. Then these fast electrons are sent on a narrow rollercoaster ride through the so-called undulator. This tight wiggling motion causes a strong emission of short light pulses. And given the high energy that these electrons have this means X-rays.

The benefit of these X-ray lasers is that you can get an extremely high imaging resolution combined with these very short exposure times, along with extremely high intensities. That for the first time opens the door to X-ray studies of dynamic processes at resolutions down to the atomic scale. In biological samples, this might be useful to understand molecular processes. In physics, one could study how atoms in a crystal move, for example in response to electric fields.

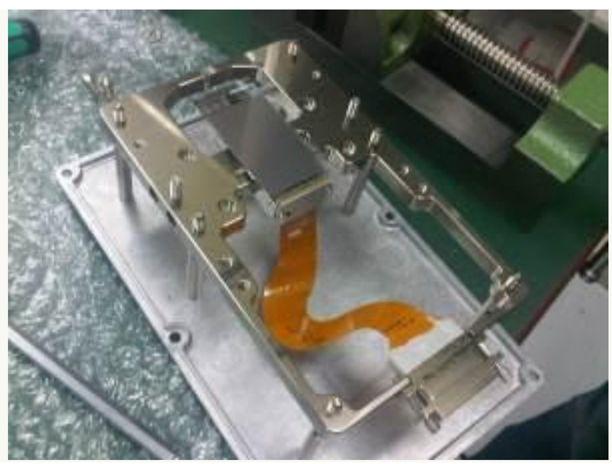
Given such clear benefits, it is no surprise that there are several X-ray free-electron lasers that either just started operating or are about to become operational. The first one for high-energy X-rays was LCLS, which at the moment enjoys the benefit of being the first off the marks. XFEL in Hamburg, Germany and XFEL at SPring-8 nearHimeji in Japan are the next ones to follow. Last year I had the privilege to visit the XFEL in Japan when it was under construction. This gave me the opportunity to look inside the machine at sections that are usually off-limits. Below are some of the photos I took. Click on the photos for a larger version.

The long accelerator line. electrons are accelerated over a distance of more than 400 meters. Once accelerated the electrons are fed into the undulators.

The undulators are being installed. The narrow stripe inside the tube, flanked by magnets, is where the electrons are sent on their wiggling path. During operation this tube is under vacuum.



The detector apparatus that will hold the custom-made CCD chips. Note the copper cooling tubes.



One of the expensive CCD test chips. It has 512×1024 pixels. Each pixel is 50 micrometers wide – quite large, so that only 3000 photons are needed to generate a signal.

Source: http://allthatmatters.heber.org/2011/02/02/the-ultimate-x-ray-machines-are-ready-to-go/