

ATHANASSIOS KALIUDIS

“Everyone wants the X-ray revolution”

Extremely high-resolution X-ray images are incredibly complex and expensive to produce, so they are seldom used. This is why current X-ray images still bear the look of the first images ever taken a hundred and twenty years ago. And this is why, right now, Professor William Graves works towards the X-ray revolution.

You’re working on an X-ray light source that costs several million dollars and is the size of a living room. Who would want something like that? Everyone. **Everyone?** Well, perhaps not everyone ! But certainly anyone who wants to peer inside objects, animals or people without actually opening them up. **But can't we already do that?** What's so special about your X-ray light source? It fills a huge gap in the market. On the one hand, we have the standard X-ray machines you see in hospitals and doctors' offices. But their resolution and brightness have barely improved since Wilhelm Conrad Röntgen's time, which was about a hundred years ago. On the other hand, you have researchers who have succeeded in creating much better X-ray light sources for scientific use called X-ray free electron-lasers, or XFELs. Their brightness is about a billion times greater than the machines doctors use. Scientists can use the beams to illuminate processes at the molecular and atomic level, so there's no doubt that XFELs are pretty amazing. **Do I detect a “but”...?** Well, the problem is that XFELs cost over a billion dollars to purchase and 100 million dollars annually to operate, essentially because they work only as part of particle accelerators that are kilometers in length. So where does that leave us? Basically, with a really good but incredibly expensive technology that is accessible to only a few people at one end of the scale, and a virtually obsolete technology for widespread use in doctors’ offices at the other. The gap I’m referring to lies somewhere in the middle.



William Graves is an Associate Professor in the Physics Department and the Biodesign Center for Applied Structural Discovery at Arizona State University. Soon he will be constructing a revolutionary X-ray light source in a new building that is currently being erected on the ASU campus. (Picture: Marc Mintz)

How do you propose to plug that gap?

By building a high-quality X-ray light source that matches the quality of an XFEL. The difference is that it will be just ten meters long and cost just a few million dollars. We call it a compact X-ray light source. It's aimed at researchers working at universities and in industrial labs, and of course doctors in major hospitals. It's set to have a significant impact on medicine and research.

What new things will your X-ray light source be capable of? First, it makes high-quality X-ray sources available to a much wider group of people. That's what will lead to new applications, new knowledge and other developments. Our X-ray sources will enable extraordinarily high-resolution medical imaging, allowing us to create videos and images of things inside the body, such as different types of soft tissue. That will help doctors spot things such as tumors and arterial blockages - and even allow them to determine whether those tumors and blockages are dangerous or not. We'll also be able to overcome a constraint that has long saddled medical imaging: high-quality X-rays have virtually no negative impact on the body, so people will be able to get as many X-rays as they need. And second, it overcomes a severe shortcoming of the big X-ray facilities, which is lack of phase coherence, so that it can improve even their performance by a factor of 100. Are there any other potential applications?

How much time do you have? (smiles) There are myriad possible uses in research and development. Scientists working in pharmaceutical research, for example, will suddenly have access to a simple method of studying the molecular structure of different proteins. The same will apply to materials research at universities and corporate labs. Engineers in the semiconductor industry are currently working blind when they develop semiconductor architectures, but high-quality X-ray sources will finally enable them to see again. Galleries and auction houses will be able to use X-ray spectroscopy to examine paintings and verify they are the genuine article. In fact, this technique has already been used in Australia on an impressionist masterpiece by Edgar Degas to reveal a second painting of his hidden underneath. Archaeologists will benefit too, because it will enable them to determine the material composition of artifacts and improve their methods of dating them. As you can see, there are lots and lots of potential applications; all sorts of small, hidden things will suddenly become visible.

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What's the technology behind it? X-rays are produced when high-speed electrons are suddenly decelerated. In a particle accelerator, or synchrotron, researchers slow down an electron beam by deflecting it into an undulator using strong magnets and forcing it along a wave-like path. An undulator consists of two rows of magnets with alternating poles across the beam path. As electrons pass through the gap between the two rows, the undulator "wiggles" them from side to side, causing them to emit X-rays. But this process works only if the electrons are already traveling at an extremely high energy when they enter the undulator – and that's why you need particle accelerators that are kilometers long. We take a different approach. Our electrons can be lower energy, because we simply wiggle them faster using laser pulses in place of undulator magnets. **You might have to explain that.** Laser pulses are electromagnetic waves, so they also have a magnetic field. That's what we use. A standard magnet component in an undulator is about three centimeters long. So you need three centimeters just to make an electron wiggle once. But with picosecond laser pulses we can get the same wiggle effect over a distance of just one micrometer, which is thirty thousand times shorter. That makes the wiggling motion thirty thousand times faster, so all we need in the end is a very straightforward and not particularly powerful particle accelerator just one meter long. We focus the electrons with magnets that take up another nine meters, and what comes out the other end are photons with a wavelength in the X-ray range – just like you get from an XFEL.

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What capabilities must the laser have to make all that work? The laser is the key to the whole system. Since the pulses are meant to be imitating a fixed undulator field, we need a laser source that is incredibly stable in all kinds of different ways. The repetition rate has to be constant and at least one kilohertz. The laser must always deliver exactly the same amount of energy in each individual pulse, and we can't have the pulses straying from their path – we need maximum target accuracy. Plus, of course, the timing of the pulses has to be just right. TRUMPF Scientific Lasers in Munich was the only company that showed us they were capable of meeting those demanding stability requirements. They developed this new laser in close consultation with us over a two-year period. It took a bit longer than we had hoped, but the results are superb, and we're delighted to have TRUMPF as a partner. **When will people be able to order the X-ray machine?** Right now we're putting

the system together at our institute with the help of various companies and hospitals. It's always difficult to predict when the test phase will come to an end and we'll be ready to market the product. But I think our compact XFEL will be available for anyone to buy within five years or less. **Where does your enthusiasm for X-rays come from?** I'm obviously interested in X-rays, but my motivation actually stems from something quite different. When I was 20, I didn't really know what I wanted to do with my life. I had a real thing for singular, high-spec cars, so I spent ten years tinkering around with Ferraris during the day and taking physics courses in the evening. I soon realized that I really liked elaborate machines with complex mechanisms! Then I got a new job through friends and started working as a technician at a particle accelerator – a job that involved even more complex mechanisms. My passion for the physics of beams led me rapidly to a PhD so that I could spend even more time working on complex machines. That's essentially what the compact X-ray light source is, too: a singular series of complex mechanisms. You could even call it my own personal Ferrari!



William Graves. (Picture: Marc Mintz)



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