The Historical Development, Scientific Opportunities, and Challenges of X-ray Free Electron Lasers

Chi-Chang Kao
SLAC National Accelerator Laboratory

The development of X-ray Free Electron Laser (XFEL) is a fascinating story of scientific ingenuity. It started from the dream of generating 1 Å coherent emission from a large number of electrons, and progressed with an interplay over 50 years between advances in theoretical concepts and experimental demonstrations, and eventually the fully self-consistent theory that led to the high-gain theory of XFEL.

The first XFEL, Linac Coherent Light Source (LCLS), achieved successful lasing in 2009, with an initial wavelength range of 1.5–15 Å. From there, progress has been truly breathtaking. Over the past decade, we have witnessed the rapid demonstration of the theoretical predictions of XFEL performance, including a 109 increase in peak power, femtosecond pulse duration, polarization control, tailored bandwidths near the Fourier transform limit, and full spatial coherence. New XFEL facilities are now operational or in development around the world.

Over time, we have also learned about the challenges in bringing the capabilities of XFELs to serve the scientific community. To start, there is very limited access to XFEL facilities because only up to a few experiments can be operated simultaneously. The scale and complexity of XFEL experiments are also much greater than we were used to. For example, a typical XFEL experiment requires coordination with the accelerator scientists to generate the required properties of the X-ray beam, along with ultrafast laser scientists to tailor, synchronize and measure the pump laser with respect to the X-ray beam to achieve the extreme time resolution, and integration of a complex detector and real-time data analysis system to ensure full use is made of the scarce beamtime.

There are many valuable lessons we can learn from the particle physics and astronomy communities, who have successfully increased the scale and complexity of their experiments over the past few decades, and fully integrated the design of new sources, detectors, and data analysis into their experiments.

In this presentation, I will review the development of XFEL, select science highlights to illustrate the capabilities of XFEL, and discuss the challenges we need to address to realize the full potential of XFEL.