Free Electron Lasers and You: An LCLS Primer

December 5 2008, by Daniel Ratner

(PhysOrg.com) -- In a few short months, the Linac Coherent Light Source will start operation as the world's first hard X-ray free electron laser, pushing SLAC National Accelerator Laboratory to the frontier of photon science. Using SLAC's linac to drive a free electron laser, or FEL, the LCLS will generate X-rays an eye-popping 10 billion times brighter than the current cutting-edge technology, while simultaneously providing pulses lasting less than one millionth of one billionth of a second.

How does an FEL accomplish these feats of X-ray wizardry? Although it reaches nearly two kilometers end-to-end, the LCLS contains the same basic components as a pocket laser pointer: an energy source, a light source, a monochromater to select a single wavelength and an amplifier. The energy source provides the power, which the light source uses to generate X-rays. The monochromater and amplifier give the X-rays the ultra-bright, coherent properties of a laser.

The LCLS pulls its energy from electrons accelerated in the final kilometer of the SLAC linac. The 14 GeV electron beam is so powerful that the LCLS requires less than 0.1% of the linac's energy to create 10 billion watts in X-rays.

X-rays, like visible light and radio waves, are rippling patterns of electric and magnetic fields, moving through space at the speed of light—the only difference is the wavelength, the distance between the ripples. All these forms of light are created when electric charges change speed or direction. To generate X-rays, the LCLS bends the linac's electron beam, the same principle behind the Stanford Synchrotron Radiation Lightsource and many other modern radiation sources. While a simple curve in the electrons' path produces light, to select a single wavelength, the LCLS uses an undulator, a series of alternating magnets that force the electrons along a precise, oscillating path. The curving electrons move neither as fast nor as straight as light, so after each undulator oscillation, or period, the electrons slip behind the X-rays. For one special X-ray wavelength, exactly equal to the slippage distance, the electrons and X-rays remain locked together after every period; by the end of the undulator, only X-rays of this precise resonant wavelength remain. (For the LCLS, this resonant wavelength is just 1.5 Angstroms, as small as the scale of atomic and molecular structures.)

Typical laser amplifiers bounce light back and forth using mirrors in a small cavity, but X-rays just pass through most mirrors. In place of a cavity, the LCLS sends the electrons on a single-pass down an enormous undulator, 3000 periods long. Traveling through the undulator, the electrons produce X-rays, the X-rays in turn push around the electrons, and by the end of the football-field-length undulator hall, the electrons are neatly bunched into groups one wavelength apart. In contrast to SSRL, where each electron emits X-rays independently, the bunched LCLS electrons emit radiation in lockstep. This cooperation amplifies the X-ray brightness by the number of bunched electrons, a factor of one million for the LCLS.

(Those keeping track of my math will note I'm a factor of 10,000 short of my claimed 10 billion-fold amplification. The LCLS also benefits from approximately 100-fold better electron beam quality and 100-fold higher current.)

What will SLAC do with this monster of a light source? Imaging single protein molecules and ultrafast atomic processes, to name just two proposals, have biologists, chemists and physicists chomping at the bit. With the LCLS reaching uncharted regions of X-ray speed and brightness, likely no one has yet to conceive of the instrument's most exciting potential. Stay tuned for ground-breaking science to come!

Interactive map of the Linac Coherent Light Source: lcls.slac.stanford.edu/FacilityMap.aspx

Provided by SLAC National Accelerator Laboratory

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