### AMO Particle Imaging Experiment

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**Brief Summary:**

Direct measurements of the size and shape of individual free clusters have not previously been possible. With the high intensity short duration of the LCLS pulse, it will be possible to obtain small angle x-ray scattering patterns from individual particles using soft x-ray photons and directly observe some information on the geometry of the particle. Time-resolved studies of evolving geometries, i.e. clusters undergoing Coulomb explosions, would be a particularly interesting capability of such an instrument at the LCLS.
Change History Log

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1. Introduction and Scientific Justification:

The goal of the particle imaging end-station is to perform small angle x-ray scattering (SAXS) on free particles in the x-ray FEL beam. While SAXS measurements of aggregates in the gas phase have been carried out previously at 3rd generation synchrotrons, the increased average brightness of the LCLS will allow more dilute species to be studied and, more importantly, the short pulse of the LCLS will allow the temporal evolution of processes that affect the size and shape of the aggregate to be studied in detail. For example, the temporal evolution of the Coulomb explosion of a cluster following irradiation with a high powered laser (Ditmire, Tisch et al. 1997) could be examined with 100 fs resolution. Alternatively, the evolution of other temporally dispersive phenomena such as molecular alignment (Stapelfeldt and Seideman 2003) can be studied directly in the time domain for molecules of sufficient size or number density to produce a measurable signal.

Figure 1: Schematic of the instrumentation used by T. Moller's group to measure SAXS spectra of free clusters (de Castro, Bostedt et al. 2007).

Preliminary research in this field has been carried out by the group of Thomas Möller (T.U. Berlin) using the FLASH FEL (de Castro, Bostedt et al. 2007). In a series of recent experiments they illuminated large clusters of Argon (average radius 32nm) using 32 nm FEL radiation using an experimental apparatus that is represented schematically in Figure 1. FEL radiation, traveling from left to right in the figure was incident on clusters that emerged from the nozzle and was skimmed with a two stage skimmer system. The VUV FEL radiation was scattered by the clusters when they were present at the time an FEL pulse passed by. The scattered radiation was converted to visible light with an MCP amplified phosphor screen detector and imaged with a CCD outside vacuum that imaged the phosphor screen via an angled mirror and vacuum viewport. The MCP, phosphor screen and mirror all had holes in them for the FEL beam to pass through without affecting the measured signal.
Results were obtained for both single clusters and a gas of ~100 clusters in the beam. The results were both as expected with some surprises. Single clusters yielded well behaved scattering patterns, but occasionally patterns corresponding to twinned clusters were observed. Current models of van der Waals cluster formation in supersonic expansions do not include mechanisms for dimer formation in the jet. Other surprising results included inconsistencies in the expected and observed cluster sizes, etc. It is clear from Figure 2, that with the limited angular acceptance of the detector used in these experiments (±60º) they are limited to particles larger than ½ the wavelength of the radiation. Scattering from smaller particles, therefore, will require shorter wavelengths.

It is worth noting here that the very successful coherent imaging program at FLASH uses very similar techniques for their imaging studies of picoplankton. Rather than convert the VUV radiation to visible light with an MCP/phosphor screen, however, the VUV light is reflected directly onto a CCD using a multilayer focusing mirror after the interaction region (Chapman, Barty et al. 2006). The slow rate of the CCD limits their experiments to rates of ~0.5 Hz.

Figure 2: Intensity of the scattered VUV light from different sized clusters as a function of the scattering angle. The scattering image from a single cluster is shown in the inset. (de Castro, Bostedt et al. 2007)
2. LCLS Particle Imaging Experiment:

To conduct particle imaging experiments at the LCLS an experiment set-up similar to that used by T. Möller’s group at FLASH would be constructed as shown below in Figure 4. Particles from a gas jet would be introduced into the interaction region where they would be illuminated by the FEL beam. Scattered radiation would be detected on a phosphor screen after amplification with a pair of multichannel plates (MCP). The phosphor screen would be imaged by a CCD camera operating at 120Hz from outside vacuum via a mirror behind the screen. Holes in the MCP, phosphor screen and mirror would allow the unscattered FEL radiation to pass through the detector and on the diagnostics chamber. Apertures might be required before the interaction region to ensure a well-collimated beam and to remove any diffuse scattered radiation from the upstream optics. With appropriate differential pumping it should not be necessary to use thin windows to separate the chamber from the upstream optics.

3. Specifications:

3.1. A vacuum chamber similar to the high field physics chamber would be used with modifications to accommodate the hardware required to acquire scattering images.

3.2. The vacuum requirements in the experimental chamber would not be as stringent as those for the high-field physics experiment, as appreciable numbers of atoms – on the order of the number of atoms in the cluster being imaged – would need to be present in the beam to interfere with the signal.

3.3. One electron TOF (the 54.7º spectrometer) would be retained in the particle imaging chamber as a diagnostic of the interaction of the FEL pulse with the target cluster.

3.4. An ion spectrometer would be included in the chamber, although a larger clear aperture would be needed to prevent the electrodes from interfering with the scatter radiation.
3.5. A gas jet and skimmer assembly similar to that used in the high field physics experiment
would be used.
3.6. The multiple skimmer version of the gas jet would be required to reduce the sample density
in the interaction region to usable levels of one or a few particles in the interaction regions
for a given shot.
3.7. Magnetic shielding will need to be modified to accommodate the large detector mounted
from the back of the chamber.
3.8. Also important to the LCLS particle imaging experiment is a means to bring in a laser
coincident with the FEL beam. A port before the chamber with a mirror to direct the beam
along the FEL path should be included in the particle imaging design, together with ports
oriented along the transverse directions.

Figure 4: A more detailed sketch of the hardware used to measure x-ray scattering from the sample (taken from (de Castro, Bostedt et al. 2007)).
4. References:


