Simulation on charge states evolution of XFEL heated target

Min Sang Cho[1,2] and Byoung-ick Cho[1,2] *

[1] *Department of Physics and Photon Science, Gwangju Institute of Science and Technology, Gwangju Korea*

[2] *Center for Reltativistic Laser Science, Institute for Basic Science, Gwangju, Korea*

* E-mail : bicho@gist.ac.kr

Gwangju Institute of Science and Technology

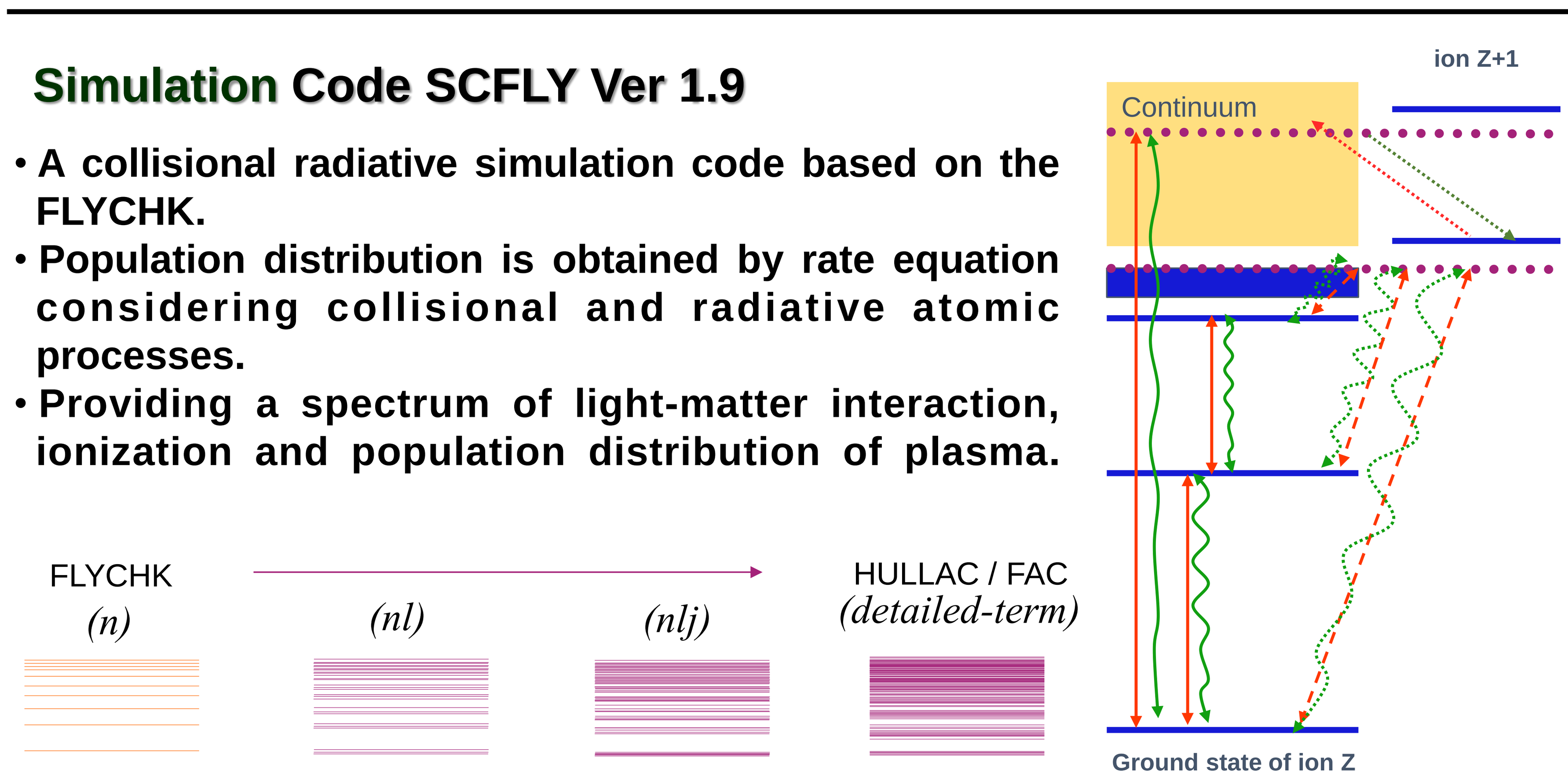
Introduction

Since X-ray Free-Electron Lasers (XFELs) opens up new regimes in x-ray—matter interactions, there have been several discoveries of nonlinear optical phenomena in the soft and hard X-ray regions at XFEL facilities. One of the interesting phenomena is the initial phase of transformation of solid density aluminum plasma by analyzing time-resolved extreme ultraviolet (XUV) absorption spectroscopy with a time resolution of 10 fs or less. The material state is produced with XFEL via K-shell photo-absorption and probed by a few fs XUV pulses at various delays. XUV absorption edges are directly related to ionization energies of core electrons (ex. Al L-level) and electron distributions at the continuum. In order to verify the mechanism, XFEL heating is modeled using the collisional-population kinetic code SCFLY. We calculate the temporal evolution of charge states and temperature of 200 nm aluminum irradiated with 5 keV XFEL pulse of 10 fs duration. This calculation could show the ultrafast dynamics of inner-shell electrons, and electron thermalization during intense XFEL – matter interaction.

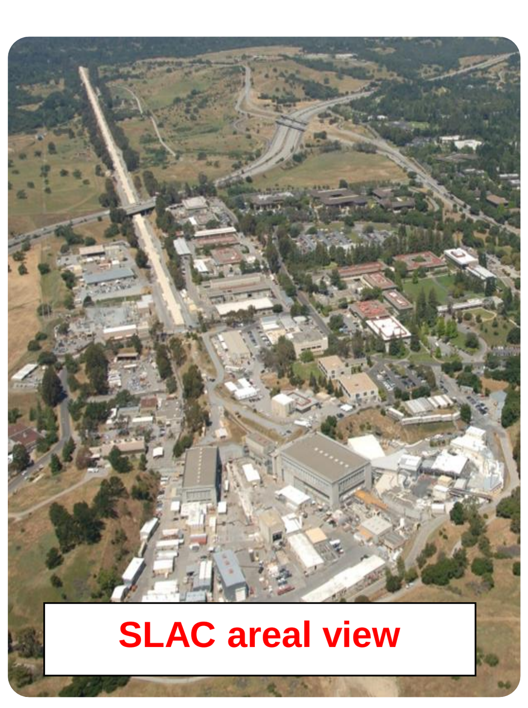
Simulation code and condition

Simulation Code SCFLY Ver 1.9

- **A collisional radiative simulation code based on the FLYCHK.**
- **Population distribution is obtained by rate equation considering collisional and radiative atomic processes.**
- **Providing a spectrum of light-matter interaction, ionization and population distribution of plasma.**



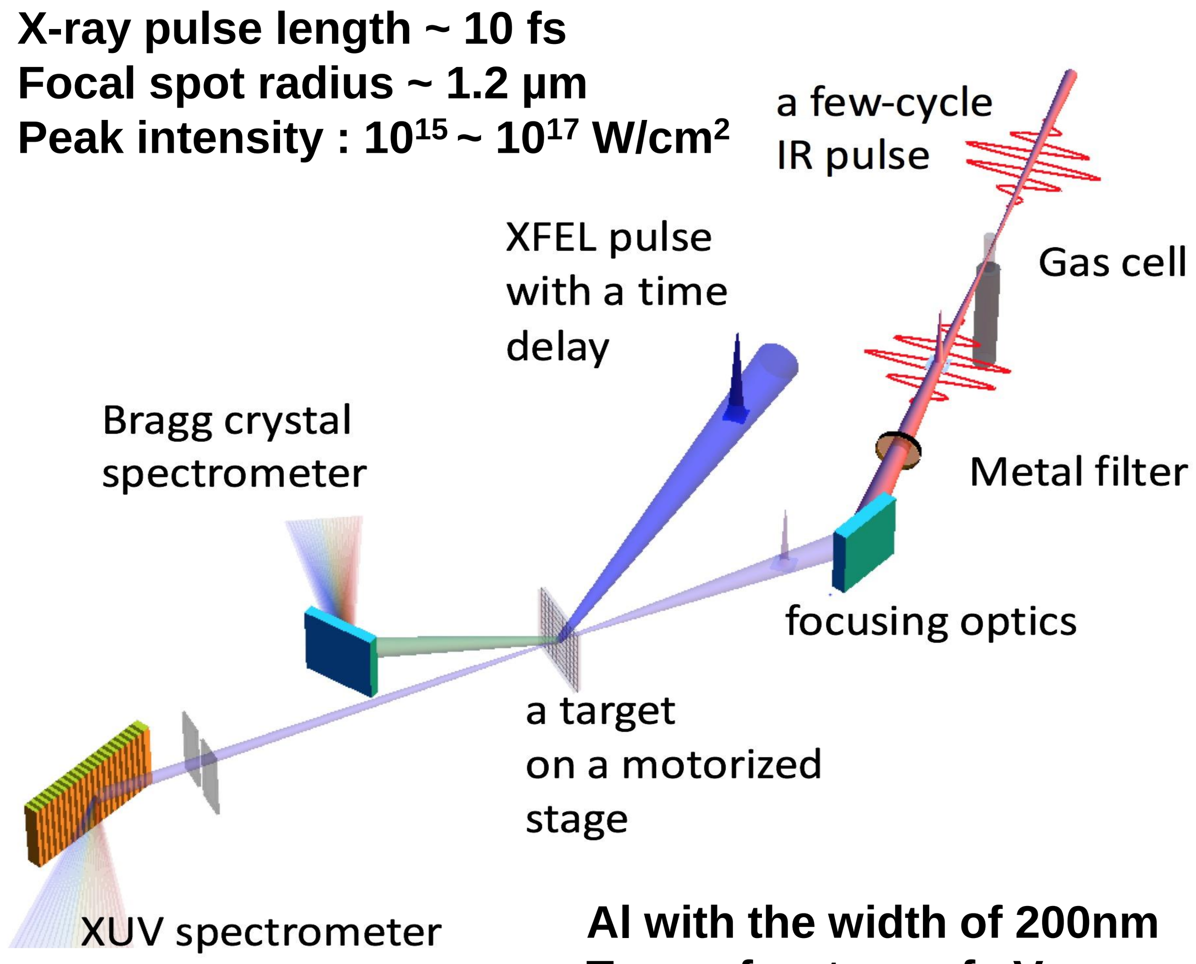
Simulation condition



XFEL Character in LCLS

- **X-ray photon energy : 5000 eV**
- **X-ray pulse length ~ 10 fs**
- **Focal spot radius ~ 1.2 μm**
- **Peak intensity : 10^{15} ~ 10^{17} W/cm²**

Peak intensity
10^{16} ~ 10^{17} W/cm²



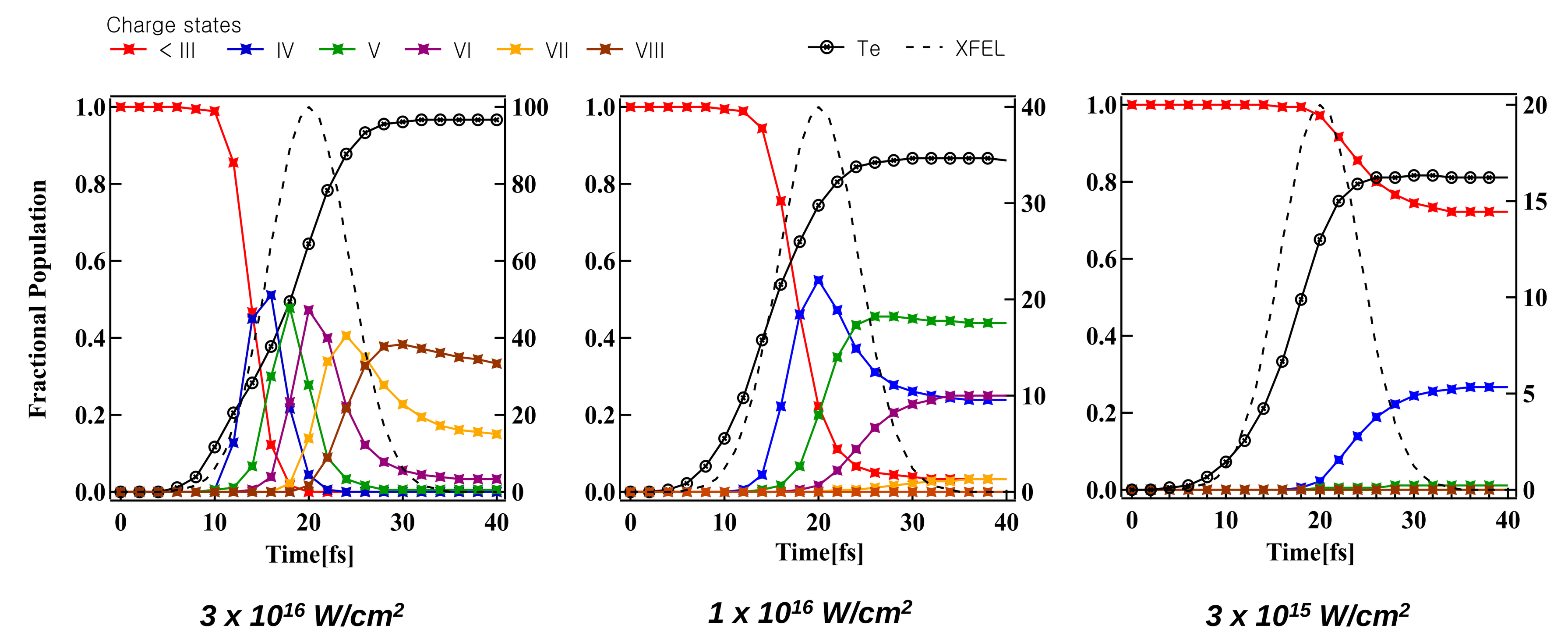
Al with the width of 200nm
Te ~ a few tens of eV

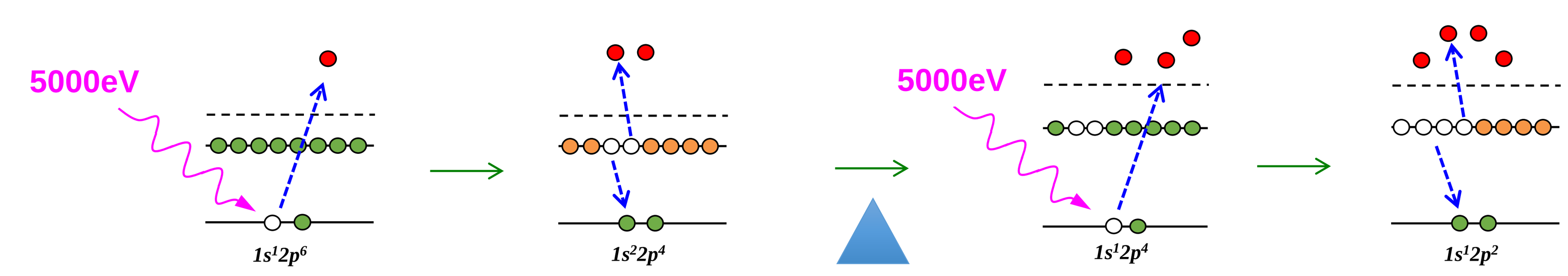
Simulation results

Temporal evolution of Al charge state for various XFEL Intensity

- **XFEL pulse, assumed as a Gaussian with 10 fs FWHM, is plotted as dash line.**
- **When the peak x-ray intensity is high (1x10^{16} W/cm²), very high charge states, such as N- or B-like Al, could be developed with an electron temperature ~ 100 eV.**
- **With a relatively low intensity (3x10^{15} W/cm²), ionization is limited to the charge state IV (F-like), and higher charge states are barely generated.**

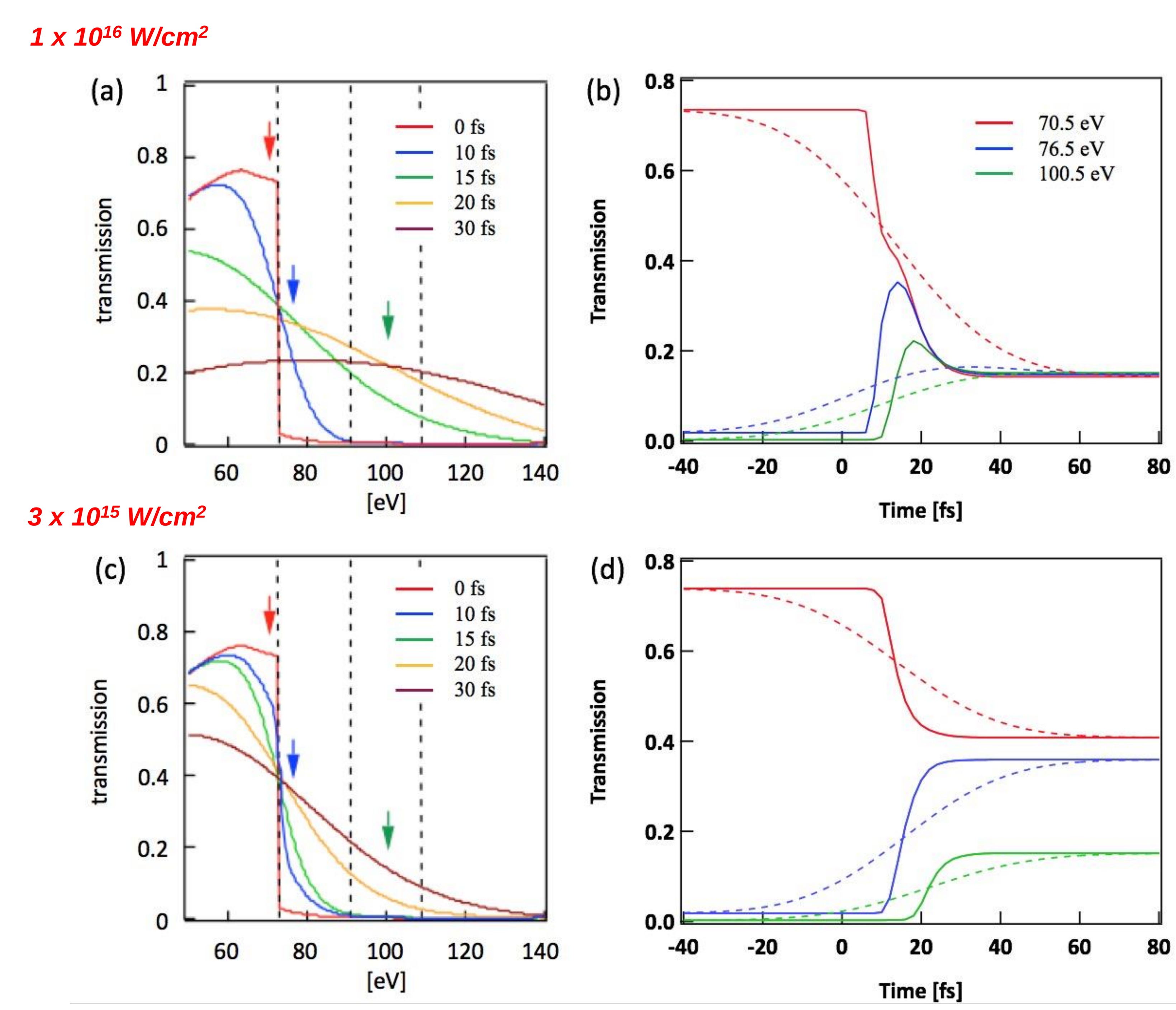
Simulation results





Before recombination

XUV transmissions near the cold L-edge of Al at various time delays



- **(a) and (b) are for the peak XFEL intensity of 10^{15}; (c) and (d) are for 10^{14} W/cm²**
- **L-shell ionization energies for the neutral Al, F-, and O-like ions are shown as vertical dashed lines in (a) and (c).**
- **In (b) and (d), dashed lines shows the results of the convolution of simulation data with a 50 fs FWHM Gaussian distribution.**
- **When the x-ray intensity is low - early time of (a) or the entire (c), the edge broadening is the major effect.**
- **As x-ray intensity increases – later time of (a), neutral atoms are depleted, and absorption edge will be shifted to higher energy.**

Conclusion & Future works

- ❑ **Simulations show a ultrafast time-resolved XUV absorption spectroscopy can follow up the ultrafast dynamics in the early stage of electronic transitions of a solid density Al warm dense matter created by an XFEL pulse.**
- ❑ **The SCFLY simulations also explain that for XFEL intensity of 1 - 10 x 10^{15} W/cm², aluminum will be heated to temperatures of a few tens eV and that the absorption around L-edge change with a time scale of 10 femtoseconds.**
- ❑ **It will be possible to figure out the electron-electron equilibration time in warm dense matter by using laser-based HHG with XFEL technology.**