Simulations of time-resolved optical spectroscopies of biomolecules

ABSTRACT: The project's objective is the computational characterization of time-resolved optical spectroscopies of chromophores that are of great relevance from a biological and/or (bio)technological point of view. Their study requires the implementation of nonlinear time-resolved optical spectroscopies, which call for accurate simulations for fair interpretation of experimental signals. Particular attention will payed to the environmental effects and the role of nuclear motions in the nonlinear response experimentally recorded for two main classes of target systems: DNA/RNA nucleobases and retinal chromophores. Simulations of pump-probe electronic spectra along with femtosecond stimulated Raman scattering and impulsive vibrational scattering spectra will be performed by means of a multiscale computational approach, involving classical MD simulations, QM and QM/MM geometry optimizations (with DFT) and characterization of excited states with both TD-DFT and MC-SCF methods.

ABSTRACT: L'obiettivo del progetto è la caratterizzazione computazionale di spettroscopie ottiche risolte nel tempo di cromofori di grande rilevanza dal punto di vista biologico e/o (bio)tecnologico. Il loro studio prevede l'implementazione di spettroscopie ottiche non lineari risolte nel tempo, che richiedono simulazioni accurate per un'interpretazione corretta dei segnali sperimentali. Particolare attenzione sarà rivolta agli effetti dell'intorno e al ruolo dei moti nucleari nella risposta non lineare registrata sperimentalmente per due classi principali di sistemi: basi azotate del DNA/RNA e cromofori retinalici. Le simulazioni degli spettri elettronici pump-probe, del scattering Raman stimolato e vibrazionale impulsivo saranno eseguite mediante un approccio computazionale multiscala, coinvolgendo simulazioni MD classiche, ottimizzazioni geometriche QM e QM/MM (con DFT) e caratterizzazione degli stati eccitati con entrambi i metodi TD-DFT e MC-SCF.

Research Project: Understanding the photo-reaction mechanisms of biological systems is of fundamental importance for a variety of technological applications, such as the design of photochromic molecular switches and photosynthetic systems, as well as in biosensing or in the evaluation of health risks, for instance related to skin damage upon irradiation. Due to the time scale and the complexity of photo-induced phenomena, giving a coherent picture of the photoreaction pathways is challenging and the environment often plays a vital role. The photochemical phenomena are too fast for conventional spectroscopies, thus nonlinear ultrafast techniques such as time-resolved electronic and/or Raman spectroscopies are required to provide appropriate spectroscopic fingerprints of molecular events. However, the interpretation of the experimental signals is very challenging, as it originates from multiple concurring optical processes, and requires computational studies that account also for environmental effects and other contributions that determine the lineshape of experimental spectra.

The project, thus, following preliminary benchmark studies on various QM methodologies, will investigate nonlinear spectra of the target chromophores in absence of environmental effects (i.e. in vacuum and neglecting vibrational contributions). Then, since good accuracy and spectral resolution of the simulated spectra is required for a direct comparison with experimental spectra, QM/MM methodologies and vibronic modeling will be employed to account for both environmental and vibronic effects that modulate the lineshapes.

Theoretical simulations planned in this project will play, thus, a pivotal role for the detailed interpretation of the time-resolved experimental spectra.

Activity Plan:

1.1 Benchmark QM studies in vacuum
1.2 Simulations (TD-DFT and MC-SCF) of DNA/RNA nucleobases linear electronic spectra
1.3 Simulations (TD-DFT and MC-SCF) of retinal chromophores linear electronic spectra
1.4 Simulations (TD-DFT and MC-SCF) of DNA/RNA nucleobases Resonance Raman spectra
1.5 Simulations (TD-DFT and MC-SCF) of retinal chromophores Resonance Raman spectra

2 Simulations of vibrational effects by means of vibronic modeling

3 Investigations on the environmental effects
- 3.1 MD simulations in solution
- 3.2 QM/MM simulations (DFT) of selected conformations
- 3.3 QM/MM characterization (TD-DFT and MC-SCF) of electronic excited states
- 3.4 QM/MM characterization (TD-DFT and MC-SCF) of vibrational states

4 QM/MM simulations (TD-DFT and MC-SCF) of time-resolved spectra
- 4.1 Simulations of pump-probe electronic spectra of DNA/RNA nucleobases and retinal chromophores
- 4.2 Simulations of FSRS spectra of DNA/RNA nucleobases and retinal chromophores
- 4.3 Simulations of IVS spectra of DNA/RNA nucleobases and retinal chromophores