

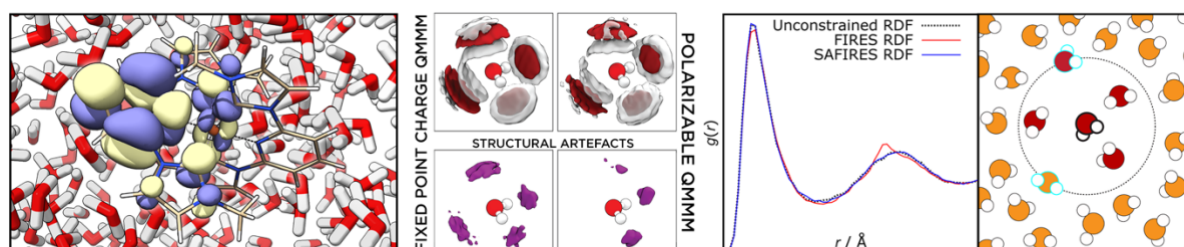
## Intertwined solute-solvent dynamics: Computational insights and advances

Coupled Quantum Mechanical / Molecular Mechanical (QM/MM) molecular dynamics (MD) simulations have proven crucial for interpreting X-ray data of light-induced transient dynamics in solvated, photofunctional molecules, which exhibit a wide range of diverse attributes, structure-function relationships, and potential applications.

As the focus moves toward processes with increasingly strong and complex solute-solvent interactions, theoretical requirements increase. We have developed a scheme that includes mutual electronic polarization between the QM and MM regions[1], which can be crucial for the description of excited states, and we confirm that it eliminates previous errors in structure and energy from the simpler coupling[2].

Furthermore, modeling processes such as solvent complexation requires QM treatment of the innermost solvent molecules. This is prohibitively costly using purely QM potentials, or creates artificial buildups of solvent in the QM/MM border region. We show how our elastic-collision-based partitioning scheme eliminates these buildups[3].

To complete the link with experiment, we have recently devised a robust strategy for identifying and eliminating finite-size effects arising when calculating X-ray Solution Scattering signals from MD simulations[4].



**Left:** Snapshot of a single frame of a QM/MM MD trajectory of a photosensitizer with its orbitals optimized under the electrostatic influence of the solvent. **Middle:** Comparison of the averaged solvation structure around water modelled with point-charge QM/MM (left), and polarizable QM/MM (right), removing discrepancies between the two single-model descriptions, improving the structural accuracy. **Right:** Radial distribution functions of water, partitioned with the previous model (FIRES), and our new method (SAFIRES), removing artificial solvent buildup in the border region.

[1]: Jónsson, E. Ö.; Dohn, A. O.; Jónsson, H. Polarizable Embedding with a Transferable H<sub>2</sub>O Potential Function I: Formulation and Tests on Dimer. *Journal of Chemical Theory and Computation*, 2019, 15, 6562–6577. <https://doi.org/10.1021/acs.jctc.9b00777>.

[2]: Dohn, A. O.; Jónsson, E. Ö.; Jónsson, H. Polarizable Embedding with a Transferable H<sub>2</sub>O Potential Function II: Application to (H<sub>2</sub>O)<sub>n</sub> Clusters and Liquid Water. *Journal of Chemical Theory and Computation*, 2019, 15, 6578–6587. <https://doi.org/10.1021/acs.jctc.9b00778>.

[3]: Kirchhoff, B.; Jónsson, E. Ö.; Dohn, A. O.; Jacob, T.; Jónsson, H. Elastic Collision Based Dynamic Partitioning Scheme for Hybrid Simulations. *Journal of Chemical Theory and Computation*, 2021, 17, 5863–5875. <https://doi.org/10.1021/acs.jctc.1c00522>.

[4]: Dohn, A. O.; Markmann, V.; Nimmrich, A.; Haldrup, K.; Møller, K. B.; Nielsen, M. M. Eliminating Finite-Size Effects on the Calculation of x-Ray Scattering from Molecular Dynamics Simulations. *The Journal of Chemical Physics*, 2023, 159. <https://doi.org/10.1063/5.0164365>.