

Vibrational spectroscopy simulation of solvation effects on the g-quadruplex



UNIVERSITÀ DEGLI STUDI DI MILANO

DIPARTIMENTO DI CHIMICA

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Abstract

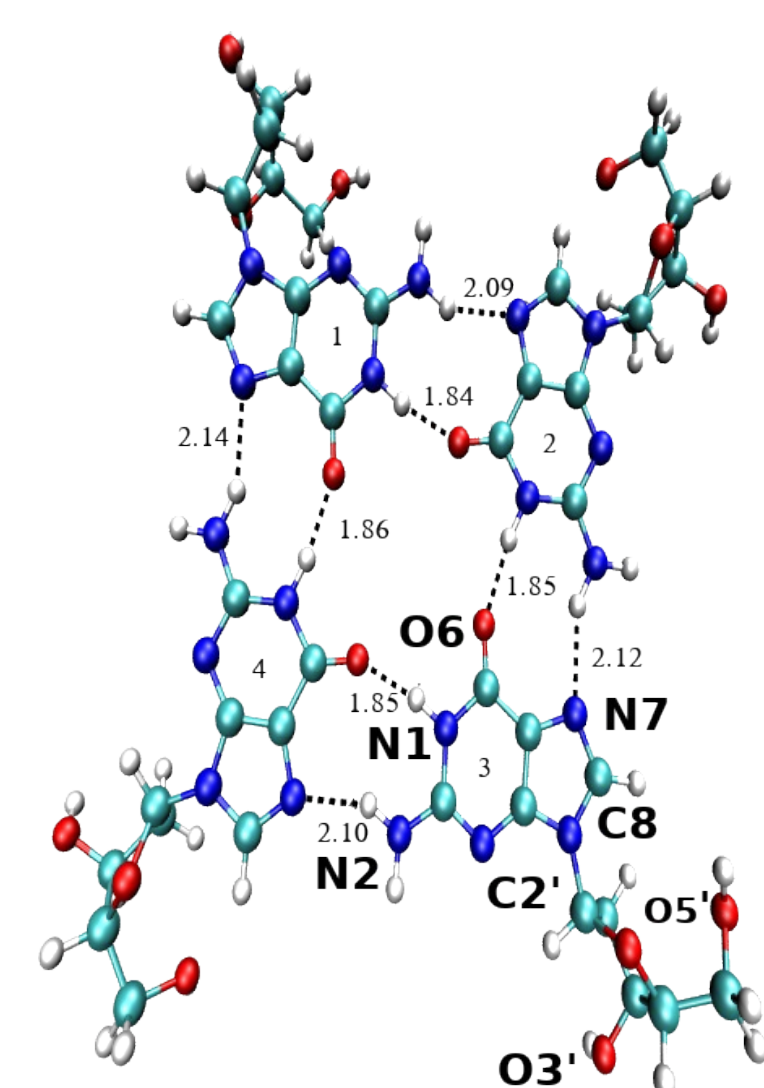
It is commonly believed that solvation of a polar molecule in a polar solvent has the only effect of red shifting all of his spectroscopical features, similarly solvating a polar molecule in a non polar solvent has the opposite effect. Naturally this can be retained valid for very simple molecular systems, but what are the effects of solvation to more complex molecular systems ?

A theoretical analysis of different kind of systems can be helpful to give atomistic insights to answer these questions, and also help develop a model which can be used to take in consideration solvation effects for complex kind of molecular systems. With this work [1] our goal is to try to understand the effects of solvation on vibrational features, in particular our work focuses on the differences that occurs between gas phase spectroscopic simulations and simulations carried on in a box of solvent.

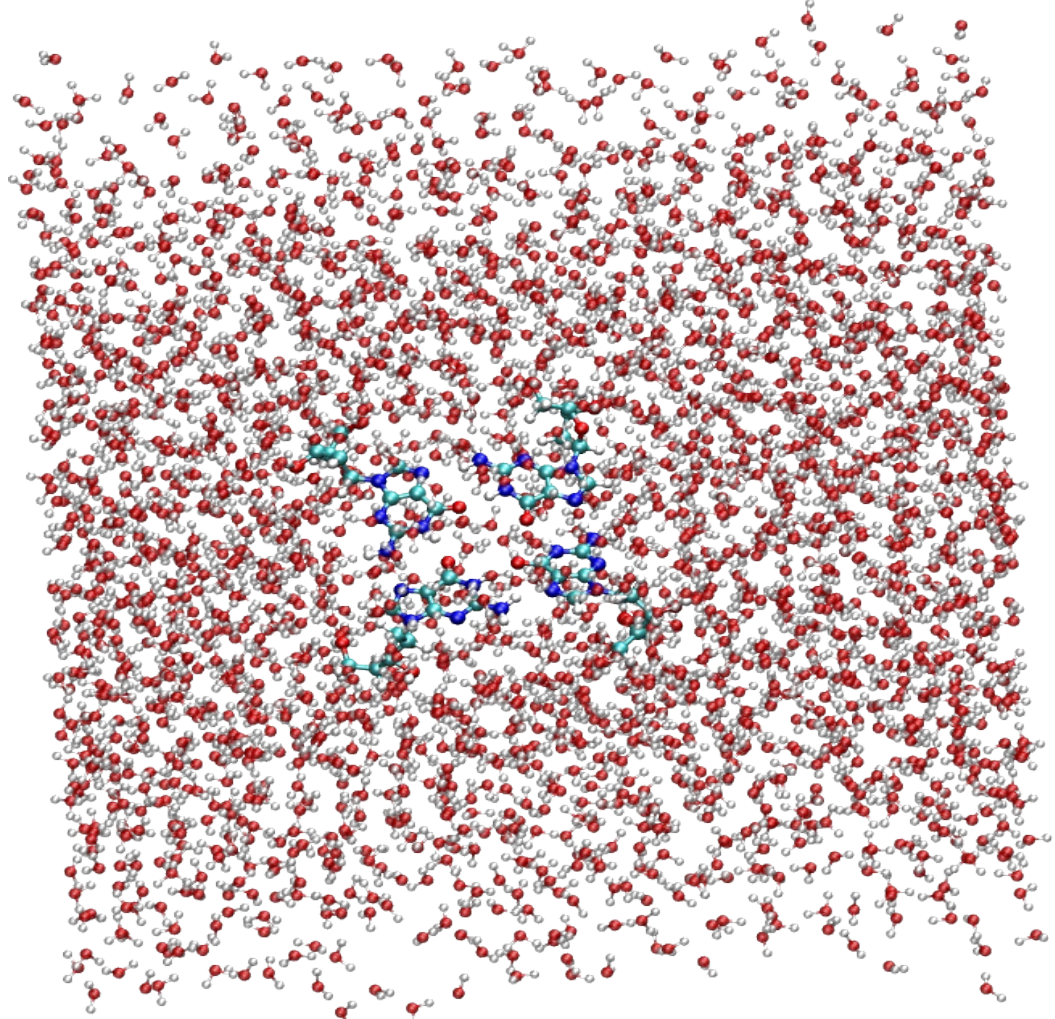
The latest one should also permit us to show that the use of an appropriate explicit solvent in this kind of simulations, is fundamental to catch the right shifts [2] caused by interaction of the system with the solvent molecule. We started our work with a simple molecule of 2'-deoxyguanosine, the informations gained from the first set of simulations has been used to show how solvation acts differently when the same molecule is found in a quadruplex geometry. In the end we will also show how the use of both classical and semiclassical [3] approaches combined with the use of Force Fields, [4,5] are able to give a good qualitative reproduction of experimental data.

Studied systems

Gas phase system



Water box system



Methods

Single and multiple trajectories with the quantum harmonic oscillator initial conditions:

$$\begin{cases} p_j(0) = \sqrt{\hbar\omega_j(2n_j + 1)} \\ q_j(0) = q_{j,eq} \end{cases} \quad \begin{cases} p_j(0) = -\sqrt{\hbar\omega_j(2n_j + 1)} \sin(\theta_j) \\ q_j(0) = \sqrt{\frac{\hbar}{\omega_j}(2n_j + 1)} \cos(\theta_j) \end{cases}$$

Classical MD with these initial conditions has been used to calculate both classical and semiclassical vibrational spectra:

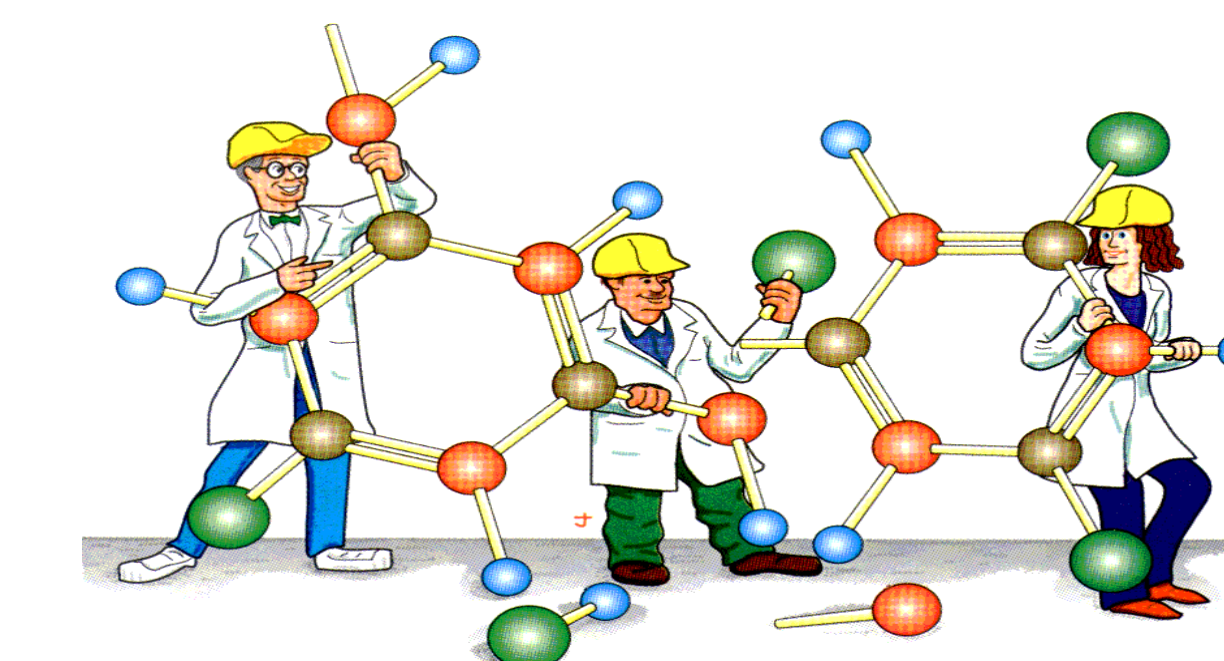
$$I_j(\omega) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} \langle p_j(0)p_j(t) \rangle e^{i\omega t} dt$$

$$I(\bar{E}) = \left(\frac{1}{2\pi\hbar} \right)^{N_{vib}} \sum_{k=1}^{N_{traj}} \frac{1}{2\pi\hbar T} \left| \int_0^T dt e^{\frac{i}{\hbar} [S_t(\bar{\mathbf{p}}_{0,k}, \bar{\mathbf{q}}_{0,k}) + \bar{E}_{k,t} + \hat{\phi}_{k,t}]} \langle \bar{\Psi}_k | \bar{\mathbf{p}}_{k,t}, \bar{\mathbf{q}}_{k,t} \rangle \right|^2$$

For the semiclassical spectrum, the Hessian matrices along the trajectory has been calculated only for the elements of the selected subspaces.

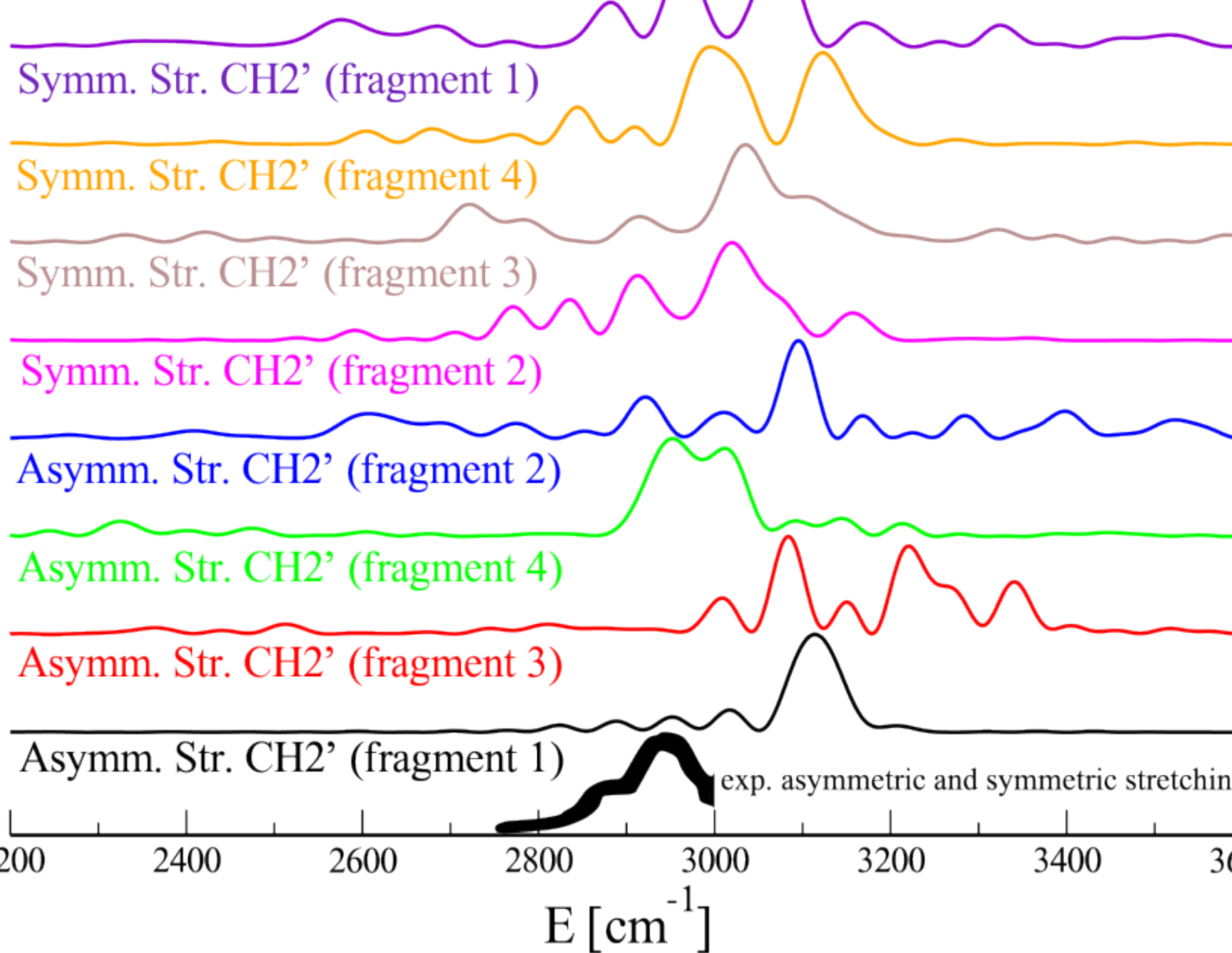
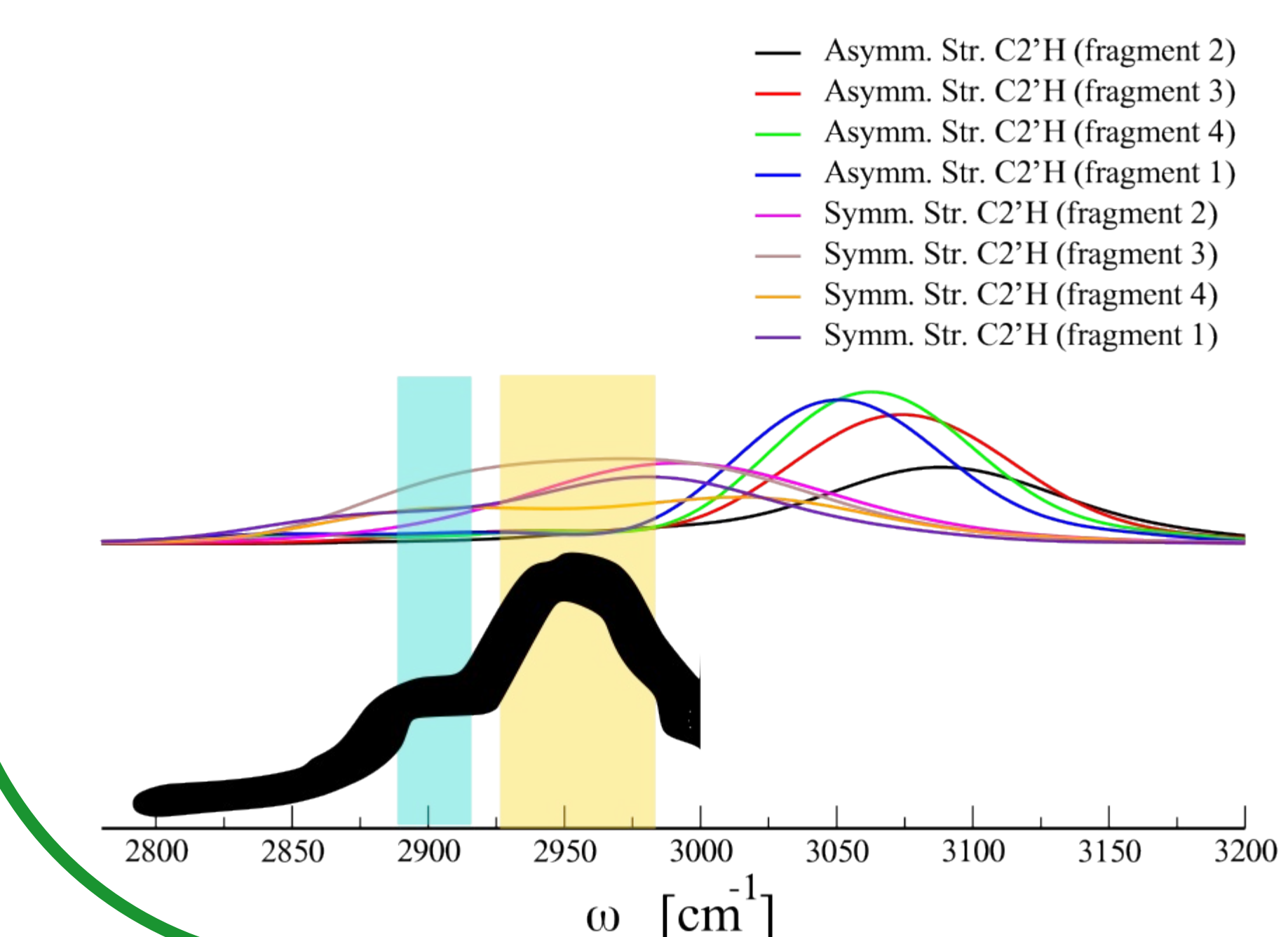
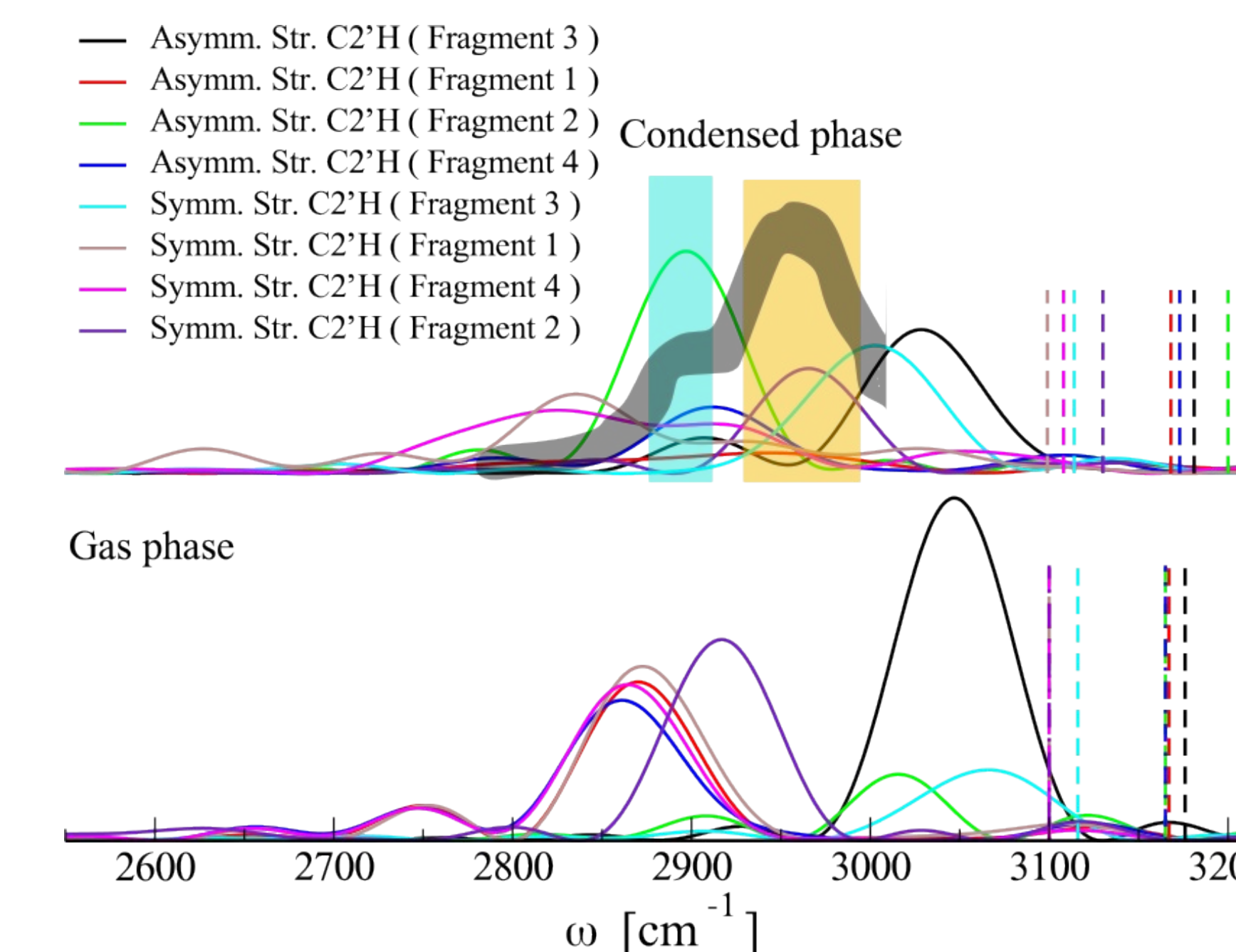
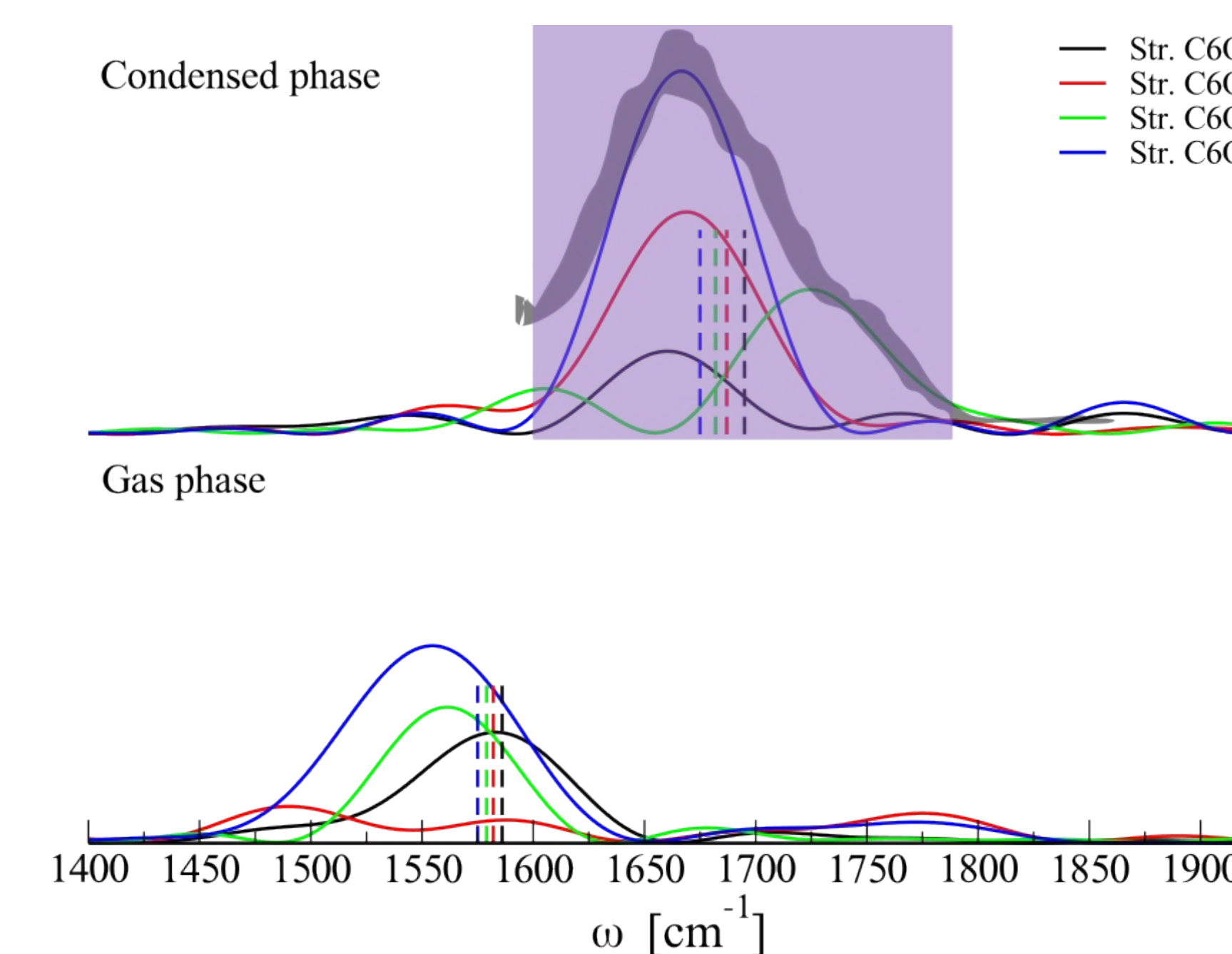
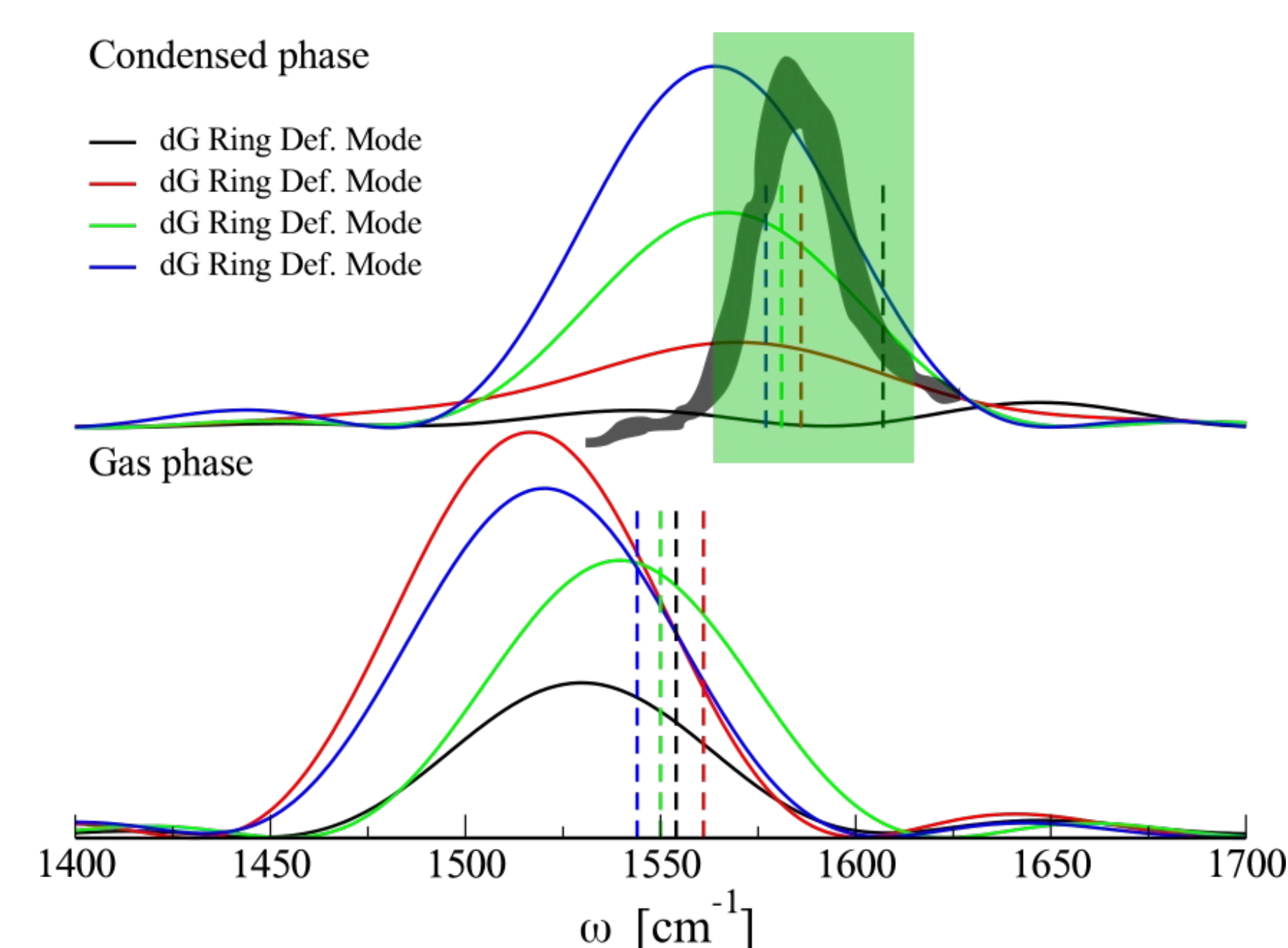
FT-CPP

MC-DC SCIVR



Tinker MM &
AMOEBA18 FF

Results



Conclusions:

- Force fields are capable to produce reliable simulated spectroscopical data
- A multiple trajectory approach in some cases is needed to better reproduce experimental data
- MC DC-SCIVR by means of a single trajectory is partially able to recover the same information obtained by running more trajectories
- Solvation cannot be accounted for just with simple shifting factors but every set of normal modes must be considered per se

References:

- [1] Davide Moscato, Fabio Gabas, Riccardo Conte, and Michele Ceotto. A theoretical vibrational spectroscopy approach on the study of solvation effects in the g-quadruplex. To be submitted, TBD.
- [2] Cynthia V. Pagba, Stephen M. Lane, and Sebastian Wachsmann-Hogiu. J. Raman Spectrosc., 41(3):241–247, 2010.
- [3] R. Conte and M. Ceotto. Semiclassical Molecular Dynamics for Spectroscopic Calculations, chapter 19, pages 595–628. John Wiley & Sons, Ltd, 2020.
- [4] Changsheng Zhang, Chao Lu, Zhifeng Jing, Chuanjie Wu, Jean-Philip Piquemal, Jay W. Ponder, and Pengyu Ren. J. Chem. Theory Comput., 14(4):2084–2108, April 2018.
- [5] Fabio Gabas, Riccardo Conte, and Michele Ceotto. Quantum vibrational spectroscopy of explicitly solvated thymidine in semiclassical approximation. J. Phys. Chem. Lett., 13(5):1350–1355, February 2022.



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