Carbon atom addition reactions in interstellar ices: 
How to marry laboratory and computational chemistry

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I will focus on surface reactions of carbon atoms on amorphous solid water (ASW) ices, mimicking the icy mantle covering the micron-sized dust grains in the interstellar medium. In the translucent stage of a molecular cloud, carbon is predominantly present in its atomic form C\(^{\text{3P}_0}\) [1] and even in dense regions it is likely more abundant than typically thought [2,3]. Moreover, already in 2001 carbon atoms additions have been proposed to lead to the formation of complex organics [4]. Therefore, a carbon atom beam source was installed at the Leiden Laboratory for Astrophysics [5], successfully demonstrating that methane can be formed from experiments of C + H on ASW [6]. In this talk I will discuss three new projects:

1. The interaction of atomic carbon with water has been extensively studied, both experimentally and theoretically [e.g., 7, 8], but particularly puzzling is the different chemical behaviour in the gas phase versus in condensed phases. I will provide a detailed explanation of the formation of \textit{formaldehyde} from carbon atoms with amorphous solid water within a theoretical framework, supported by tailored experiments [9].

2. I will touch upon the reactions of carbon atoms with molecular hydrogen and show that an intricate interplay of reactions can lead to the formation of \textit{methane}, even when H atoms are not present. I will discuss this both from an experimental and computational point-of-view and link the various intermediates to other recent studies [10].

3. Finally, I will show that the reactivity with H\(_2\) and H\(_2\)O does not restrict the formation of complex organics, and in fact the reaction between C and CO occurs so rapidly that \textit{ketene} and \textit{acetaldehyde} can be formed in the presence of H atoms [11].

References
[5] Qasim \textit{et al.}, 2020, RSI 91, 054501
[6] Qasim \textit{et al.}, 2020 NatAs 4, 781
[7] Schreiner \textit{et al.}, 2006, CPC 7, 880