Cold chemistry in hot cores: Non-diffusive grain-surface chemistry and its role in forming complex organic molecules in star-forming regions

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Reactions on dust-grain surfaces are responsible for the production of many important interstellar molecules, including gas-phase H_2, grain-surface ice species such as water, ammonia and methanol, and arguably some of the most complex molecules detected in star-forming regions. However, our view of the temperature dependence of this chemistry has recently been changing. A major driver in this shift is the gas-phase detection of complex organic molecules (COMs) such as methyl formate in cold pre-stellar cores. These detections have pushed back the astronomical clock on COM production, to a time much earlier than the warm proto-stellar stage in which they are usually detected (albeit in much greater abundance). Experimental evidence also suggests that COMs may be formed on very cold surfaces (~10 K), through mechanisms that do not require thermal diffusion of the reactants. Past models that rely solely on diffusive reaction mechanisms now appear inadequate.

I will discuss new modeling treatments [1,2] that adopt a more comprehensive framework for grain-surface and ice-mantle chemistry, allowing reactants to meet in a variety of ways that do not rely solely on diffusion. This allows COMs to form as the ice mantles grow, while processing of the ices by external and cosmic-ray-induced UV fields can also lead to COM production. The period when the water-dominated ices desorb from the grains (Fig. 1, dashed lines) also allows trapped radicals to meet and react on the warm ice surfaces, prior to desorption. Gas-phase chemistry can further enhance COM production in some cases. In combination, these processes allow COMs to form over a range of temperatures, through a variety of mechanisms. I will discuss the implications of this new picture of COM chemistry.

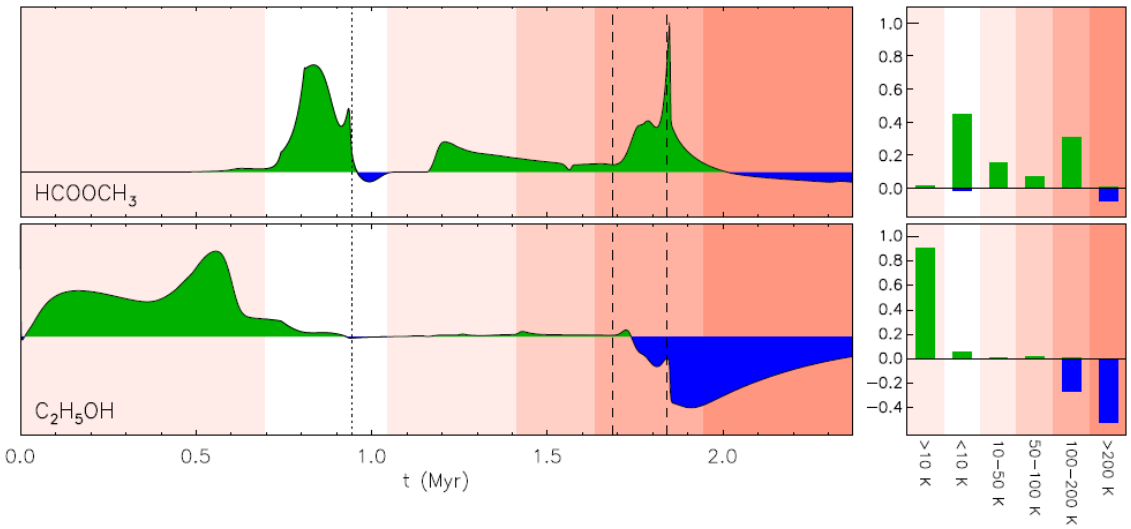

Figure 1: Net rates (arb. units) of molecular formation/destruction (green/blue), summed over all chemical phases (gas + surface + ice), from the collapse of a cold core through its evolution to a hot molecular core.

References

[1] M. Jin & R. T. Garrod, ApJS, 249, 26
[2] R. T. Garrod et al., ApJS (accepted), https://arxiv.org/abs/2110.09743