



Complex organics in protostellar disks: the first stage of a long chemical journey to planetary systems

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The role of the pre-solar chemistry in the chemical composition of Solar System bodies is far to be understood. Did they inherit at least part of their composition from the earliest stages of star formation? During each step of the process leading to the formation of a Sun-like star and its planetary system, the molecular complexity increases from simple species up to interstellar Complex Organic Molecules (iCOMs, O-, N-, S-bearing species with at least 6 atoms). In turn, iCOMs can be considered as bricks that can be used to assemble pre-biotic molecules. In this context, the study of the molecular complexity of Class 0 objects, where protostars are still deeply embedded in their parental core and still accreting their mass, is mandatory. As a matter of fact, protostellar radiation heats the surrounding medium creating the so-called hot-corinos, i.e. the regions of about 100 au with temperatures of at least 100 K, hot enough to (i) evaporate dust mantles, and (ii) trigger a warm gas phase-chemistry. As a consequence, the iCOMs abundances bloom, dramatically enriching the gas phase. The chemistry of the protostellar environments represents the first stage, and it needs to be compared with those of more evolved phase including relics of our pristine Solar System, such as comets.

The investigation of star-forming regions has enormously benefited from the recent advent of the IRAM-NOEMA and ALMA (sub-) mm-interferometers, which allowed the observers to reach Solar System scales. It is of paramount importance to combine high-sensitivity spectral surveys to collect large numbers of lines for each iCOM (for reliable identifications and to analyse excitation conditions) as well as to image their spatial distribution to investigate their association with different ingredients of the Sun-like star formation recipe (e.g. warm envelopes and cavities opened from hot jets, accretion disks, disk winds). The overall goal is to analyse the protostellar disk, i.e. the region where a Solar System will form billions of years later. The imaging of these regions with molecules simpler than iCOMs, such as CO or CS is indeed paradoxically hampered by their high abundances and consequently high line opacities which do not allow the observers to disentangle all the emitting components at these small scales.

In this respect, we will report recent results of a prototypical object such as IRAS4A, showing how complementing images obtained in the cm-spectral regime are to minimise iCOMs emission

hampering due to dust opacity. Finally, we will focus on the protostellar disk HH212, observed with a spatial resolution down to about 10 au. A large number of iCOMs, such as CH_3OH , CH_3CHO , HCOOCH_3 , $\text{CH}_3\text{CH}_2\text{OH}$, NH_2CHO , have been imaged: their emission is clearly associated with the upper and lower rings in the outer part of the disk imaged using continuum emission. Indeed, the geometry of these features has led this source to be called a "space hamburger" in the popular press. We will discuss the possible explanations: (i) the disk has a vertically extended gaseous atmosphere (the "methanol buns") and no gaseous methanol on the disk midplane (the "dusty meat"); (ii) the optically-thick disk midplane obscures iCOMs' emission. The answer is essential to understand the gas composition in the equatorial plane, where planets will form.