The chemical content of planet-forming disks: towards a comparison with comets to unveil the origin of the Solar System

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How have planets formed in the Solar System? And what chemical composition they inherited from their natal environment? Is the chemical composition passed unaltered from the earliest stages of the formation of the Sun to its disk and then to the planets which assembled in the disk? Or does it reflects chemical processes occurring in the disk and/or during the planet formation process? And what was the role of comets in the delivery of volatiles and prebiotic compounds to early Earth?

A viable way to answer these questions is to observe protoplanetary disks around young Sun-like stars and compare their chemical composition with that of the early Solar System, which is imprinted in comets. The impacting images recently obtained by millimetre arrays of antennas such as ALMA provided the first observational evidence of ongoing planet formation in 0.1-1 million years old disks, through rings and gaps in their dust and gas distribution. The chemical composition of the forming planets and small bodies clearly depends on the location and timescale for their formation and is intimately connected to the spatial distribution and abundance of the various molecular species in the disk. The chemical characterisation of disks is therefore crucial.

This field, however, is still in its infancy, because of the small sizes of disks (~100 au) and to the low gas-phase abundance of molecules (abundances with respect to H₂ down to 10⁻¹²), which requires an unprecedented combination of angular resolution and sensitivity. I will show the first pioneering results obtained as part of the ALMA chemical survey of protoplanetary disks in the Taurus star forming region (ALMA-DOT program). Thanks to the ALMA images at ~20 au resolution, we recovered the radial distribution and abundance of diatomic molecules (CO and CN), S-bearing molecules (CS, SO, SO₂, H₂CS), as well as simple organics (H₂CO and CH₃OH) which are key for the formation of prebiotic compounds. Enhanced H₂CO emission in the cold outer disk, outside the CO snowline, suggests that organic molecules may be efficiently formed in disks on the icy mantles of dust grain. This could be the dawn of ice chemistry in the disk, producing ices rich of complex organic molecules (COMs) which could be incorporated by the bodies forming in the outer disk region, such as comets.
The next step is the comparison of the molecules radial distribution and abundance in disks with the chemical composition of comets, which are the leftover building blocks of giant planet cores and other planetary bodies. The first pioneering results in this direction have been obtained thanks to the ESA’s Rosetta mission, which allowed obtaining in situ measurements of the COMs abundance on the comet 67P/Churyumov-Gerasimenko. The comparison with three protostellar solar analogs observed on Solar System scales has shown comparable COMs abundance, implying that the volatile composition of comets and planetesimals may be partially inherited from the protostellar stage. The advent of new mission, devoted to sample return such as AMBITION will allow us to do a step ahead in this direction.