Gas properties in the Early Universe deciphered from spectral surveys of high-z objects: the Cloverleaf quasar

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Observations of molecular lines in very-high redshift objects, offer a unique chance to investigate the gas dynamics and physico-chemical conditions in early galaxies, hence to understand galaxy evolution. First such detections were reported in the 1990's. They concerned sub-mm lines of CO, HCN and.HCO^+ in a few IR-bright quasars, most notably H1413+117 (z=2.56), the "Cloverleaf Quasar", whose radiation is amplified by one order of magnitude through gravitational lensing[1]. The lines, although very broad, are optically thick, and arise from the same extended region as the IR radiation[2]. The strong surrounding IR-radiation, the line opacities and very high critical densities of the sub-mm lines (>10^{6-7}cm^{-3} for HCO+ and HCN J=3-2) suggested that the observed lines were radiatively excited by fluorescent radiation[3], making the derivation of the gas properties highly uncertain.

The advent of new generation receivers, equipped with wide-band backends, on the IRAM interferometer and ALMA has drastically changed the picture. We can now carry on extensive, albeit sensitive, line surveys throughout the mm-wave atmospheric windows and may detect dozens of molecular lines in the brightest sources, e.g. the Cloverleaf Quasar.

We present here the results in that source of a 3-mm & 2-mm spectral survey made with the IRAM interferometer, and of a 3-mm survey made with ALMA. Thirteen rotational transitions (up to HCN J=6-5) pertaining to 10 different molecular species are detected with a good to fair S/N. These, allied to previous low frequency observations of the J=1-0 HCN and HCO^+ lines, are analyzed through statistical non-LTE radiative transfer calculations that include the lowest vibrationally excited states, to derive the gas properties and molecular abundances. The latter are typical of Galactic GMCs. The comparison of the line intensities of related molecular species, such as HNC, HCN and CN, whose vibrational states lie respectively 9, 15 and 16 μ above the ground state, hence span a range of 40 in intensity of the embedding mid-IR radiation, indicate that IR pumping plays a secondary role in line excitation. Consequently, the gas density is found to be very high (>10^6 cm^{-3}) throughout the warm dust emission region. The latter is resolved and extends over a few hundreds of pc. The mass of dense gas in the central region is large enough to sustain a huge star formation rate during millions of years.

References

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