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How organics deuteration changes during the formation of a Sun-like star

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Abstract. Deuterated molecules have been detected towards the early stages of Sun-like star formation (prestellar cores, Class 0 objects) as well as towards the Solar System; they are a powerful diagnostic tool for studying physical conditions at the moment of the organics formation. However, observations in intermediate stages (Class I/II objects) are still missing. In the framework of the ASAI-IRAM Large Program, we report here the formaldehyde and methanol deuteration as measured in the Class I object SVS13-A. The deuterium fractionation is found to be 9×10^{-2} for HDCO, 5×10^{-3} For D_2CO, and 4×10^{-3} for CH_2DOH, up to one order of magnitude lower than the value measured in Class 0 sources. The present measurements of organics deuteration towards the Class I object SVS13-A contribute to fill in the gap between prestellar cores and protoplanetary disks in the context of deuterium fractionation measurements (see Bianchi et al. (2017)).

1. Introduction

The deuterium fractionation is the process that enriches the amount of deuterium with respect to hydrogen in molecules. While the D/H elementary abundance ratio is 1.6×10^{-5}, for molecules this ratio can be definitely higher and can be a precious tool to understand the chemical evolution of interstellar gas (Ceccarelli et al. (2014) references therein). In particular, formaldehyde and methanol around protostars are mostly formed via active grain surface chemistry (Tielens et al. 1983) and then stored in the grain mantles to be eventually released into the gas phase once the protostar is formed and the grain mantles are heated and evaporated (Ceccarelli et al. (1998); Ceccarelli et al. (2007); Parise et al. (2006)) or sputtered by shocks (Codella et al. (2012); Fontani et al. (2014)). Deuteration can thus be used as fossil record of the physical conditions at the moment of the icy water and organics formation (Taquet et al. 2014). While deuterated molecules have been detected towards the early stages of the Sun-like star formation (prestellar cores and Class 0 objects) as well as in the Solar System (Ceccarelli et al. 2014), no clear result has been obtained for intermediate evolutionary phases (Class I/II objects). Systematic observations of D/H in Class I objects are therefore required to understand

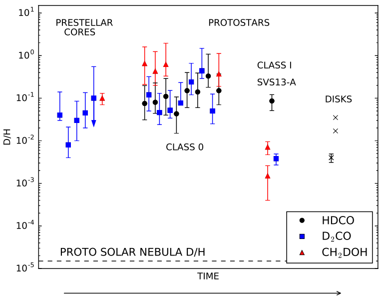

Fig. 1. From Bianchi et al. (2017, MNRAS 467, 3011, and references therein): D/H measured in prestellar cores, Class 0/I sources, and protoplanetary disks. Note that (i) deuteration in protoplanetary disks refers to HCN, HCO^+ and (ii) any trend within the classes of prestellar cores and the Class 0 protostars is not significant.

how the deuterium fractionation evolves from prestellar cores to protoplanetary disks. In this framework we present a study of formaldehyde and methanol deuteration towards the SVS13-A object, located in the NGC1333 star forming region (d = 235 pc), and thought to be a Class I system ($\sim 10^5$ yr, driving the well known HH7-11 chain). The observations are taken in the context of the ASAI (Astrochemical Survey At IRAM[1]) project, which obtained an unbiased spectral survey (1, 2, and 3 mm) with the 30-m antenna of a selected sample of template sources, which cover the full formation process of solar-type stars, from prestellar cores to protoplanetary disks. The project joins the efforts of specialists in astrochemistry to a complete census of the gas chemical composition, and its evolution along the main stages of the star formation process.

2. Organics deuteration around SVS13-A

The ASAI data show a forest of emission lines towards SVS13-A. For this reason we applied several criteria for the lines identification, such as the line profile shape, line blending and consistent FWHMs. All the identified lines show a typical peak velocity of $\sim$ 8–9 km s^{-1} (v_{sys} = +8.5 km s^{-1}). The lines have been mainly detected at 1mm, due to a beam filling factor effect (HPBW $\sim 10''$, $20''$, $30''$ at 1, 2, 3 mm, respectively). We detected several lines of formaldehyde and methanol isotopologues such as $H_2{}^{13}CO$, HDCO, D_2CO, $^{13}CH_3OH$, CH_2DOH, CHD_2OH and CH_3OD. The observed lines cover a wide range of excitation, up to $E_u \sim 200$ K , with typical FWHM of $\sim$ 2–4 km s^{-1}. We use the derived column densities to measure the D/H ratio which is $9 \pm 4 \times 10^{-2}$ for H_2CO and $7 \pm 1 \times 10^{-3}$ for CH_3OH. For D_2CO we obtained D/H $\sim 5 \times 10^{-3}$. Interestingly, the CH_2DOH/CH_3OD ratio towards SVS13-A is $\sim$ 3.2, a value consistent with the grain chemistry statistical value (Osamura et al. 2004).

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3. Conclusions

Using both LVG analysis and rotation diagram approach we derived for formaldehyde isotopologues low temperatures ($\sim$ 20 K) and a large emitting size ($5''$) suggesting the association with the molecular envelope. Methanol emission suggests instead the association with a hot-corino with high densities ($> 10^6$ cm^{-3}) and temperatures ($\sim$ 80–190 K). The D/H is lower up to one and two orders of magnitude for H_2CO and CH_3OH isotopologues respectively, if compared to previous Class 0 measurements (Fig 1). This could be an indication of the modified chemical content in the evolutionary transition from the Class 0 to the Class I phase. Alternatively, it could be due to the gradual collapse of the external shells of the protostellar envelope, less deuterated because composed of ices formed in a less dense region.

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