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ALMA molecular observations of supernova 1987A

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Abstract. Twenty-six years after the explosion, we conducted a molecular line survey for supernova 1987A, using the ALMA observatory. The detection of molecules in the ejecta can uncover evidence of mixing and dynamics in the early days after the supernova explosion, as well as of molecular chemistry that took place in the last 25 years.

It is still not well understood to what extent the macroscopic mixing occurred after the supernova explosion. Molecules can provide a new tool to probe and test the extent of mixing: macroscopic mixings stir the elements from different layers of nuclear-reaction zones in the stellar core, opening the possibilities to form molecules that were composed of elements from different nuclear-burning zones, which the ALMA can detect. Additionally, the ALMA measured the line profiles of molecules, which unveiled the dynamics of ejecta. The high sensitivity observations of molecules can open a new window to determine SN explosion mechanisms and allow us to probe macroscopic mixing after the explosion.

Keywords. supernovae: individual (Supernova 1987A) – ISM: molecules – dust – (stars:) circumstellar matter – (galaxies:) Magellanic Clouds –

1. Introduction

Since its explosion, SN 1987A has unveiled how the SN ejecta has evolved over the past 27 years. Recent discoveries include the detection of a large ($\sim 0.5\,M_\odot$) mass of dust (Matsuura *et al.* 2011; 2015), that is confirmed to be ejecta in origin (Indebetouw *et al.* 2014), cold CO and SiO newly detected in millimetre wavelength (Kamenetzky *et al.* 2013), and spatial variation of synchrotron power law indices (Zanardo *et al.* 2014).

The finding of CO and SiO in millimeter wavelength opened up a new opportunity of studying molecules in SNe. During the cycle-2 ALMA observing period, we obtained molecular spectral surveys of SN 1987A, ranging between 200–300 GHz. We have detected CO, SiO, SO, HCO^+ with potential detection of ^{29}SiO.

Line profiles of SiO show a dip at the top, which is not found in CO. That can be explained if SiO molecules distribute non-spherically, and most likely in either bipolar or torus structure. The detection of HCO^+ supports the presence of mixing in early days after the explosion. In order to form HCO^+, a large quantity of hydrogen, carbon and oxygen need to be present in one place, and the only way to trigger that is mixing. The classical picture of the stellar interior composed of layers of discrete atomic zones, which were built up through different nuclear synthesis processes, would fail to form HCO^+. Detections of isotopologues provides the upper limits of isotope ratios of $^{28}Si/^{29}Si$. The direct line ratio gives $^{28}SiO/^{29}SiO>11$, and further non-LTE model analysis suggests $^{28}Si/^{29}Si> 38$. The estimated abundance ratio is consistent to predicted value by the explosive nucleosynthesis models by Woosley (1988) but higher than Thielemann *et al.* (1988).

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