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ALMA Observations of a High-density Core in Taurus: Dynamical Gas Interaction at the Possible Site of a Multiple Star Formation

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Abstract. It is crucially important to observe dense cores in order to investigate the initial condition of star formation since protostars are formed via dynamical collapse of dense cores, inhering the physical properties from their natal dense cores. Here we present the results of ALMA Cycle 0 and Cycle 1 observations of dust continuum emission and molecular rotational lines toward a dense core, MC27 (aka L1521F), which is considered to be very close to the first protostellar core phase. We revealed the spatial/velocity structures of the core are very complex and and suggest that the star formation is highly dynamical.

Keywords. ISM: clouds, ISM: kinematics and dynamics, ISM: molecules, stars: formation

1. Introduction

In low-mass star forming regions, most of the starless dense cores, whose densities are 10^{4-6} cm^{-3}, do not seem to be dynamically collapsing because the timescale statistically derived is larger than the free fall time (Onishi *et al.*2002) and because the density distribution is flat toward the peak (Ward-Tompson *et al.*1994). The subsequent evolutionary stage we can easily observe is a Class 0/I protostar phase, which shows strong outflow, indicating that the gravity is strong, and then mature protostellar cores were already formed. Recently, there have been many studies for the objects containing the first protostellar core candidate (e.g., Enoch *et al.*2010). One of such objects is MC27 (e.g, Onishi *et al.*1999, 2002) or L1521F (Codella *et al.*1997). It is one of the densest ($>10^6$ cm^{-3}) cores in low mass star formation regions (Onishi *et al.*2002) and contains one of the faintest protostars detected by *Spitzer* (hereafter, the *Spitzer* source), which indicates that it is among the youngest and still may preserve the initial conditions of star formation (Bourke *et al.*2006; Terebey *et al.*2009).

2. Observations and Results

First, we observed dust continuum emission and molecular rotational lines (e.g., HCO^+ (3–2); $H^{13}CO^+$ (3–2)) toward MC27/L1521F with ALMA Cycle 0 at wavelength of 1.1 mm (see also Tokuda *et al.*(2014)). We revealed quite complex structures at the center. We found a few starless high-density cores, one of which (MMS-2) has a very high density of $\sim10^7$ cm^{-3},

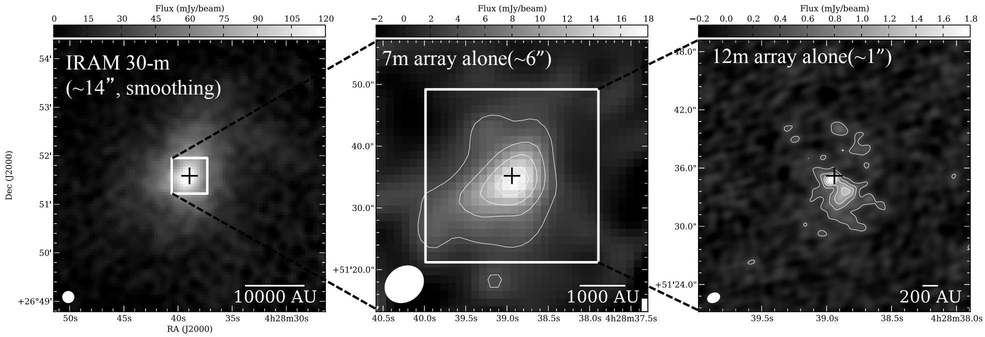

Figure 1. Distribution of 1.1 mm dust continuum emission toward MC27/L1521F. Black crosses indicate the position of the *Spitzer* source. The angular resolutions are given by ellipses in lower left corner of each panel.

next to the *Spitzer* source. A very compact bipolar outflow with a dynamical timescale of a few hundred years was found toward the *Spitzer* source. The HCO^+ (3–2) observation shows several cores associated with an arc-like structure whose length is ∼2000 AU, possibly due to the dynamical gas interaction (see also numerical simulations by Matsumoto *et al.*2015). These results suggested that dynamical gas interactions in a very early stage of star formation are a key to form the multiple (or binary) protostars.

Following the observation with dust continuum emission of 1.1 mm (Band 6) and 0.87 mm (Band 7) toward the object were carried out in ALMA Cycle 1. The Band 7 continuum observation with an angular resolution of $\sim 0.''3 \times 0.''7$ revealed that MMS-2 could be further resolved into two peaks. Three figures in Fig. 1 demonstrate the distributions of the Band 6 continuum observed by the 12m (main array) array and the 7m array (ALMA Compact Array), and the IRAM 30-m telescope. Detailed column density distribution with the size from ∼100 to ∼10000 AU scale are revealed by combining the data. Our analysis shows that the averaged radial column density distribution of the inner part ($r <$ ∼3000 AU) is $N_{\rm H_2} \sim r^{-0.4}$, clearly flatter than that of the outer part, $\sim r^{-1.3}$. We detected the above-mentioned complex structure inside the inner flatter region, which may reflect the dynamical status of the dense core.

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