GAS AND DUST CONDENSATIONS AND AN EMBEDDED OBJECT IN THE LUPUS 3 CLOUD. K. Tachihara, *Graduate School of Science and Technology Kobe University, 1-1 Rokko-dai Nada-ku, Kobe, 657-8501, Japan (tatihara@kobe-u.ac.jp)*, M. Rengel-Lamus, *Thüringer Landessternwarte Tautenburg, Sternwarte 5, 07778, Tautenburg, Germany*, Y. Nakajima, *National Astronomical Observatory of Japan, Mitaka, Tokyo, 181-8858, Japan*, P. André, *CEA Service d'Astrophysique, Saclay, France*, R. Neuhäuser, *Astrophysikalisches Institut und Universitäts-Sternwarte Jena, Schillergäßchen 2-3, 07745, Jena, Germany*, A. Mizuno, *Solar-Terrestrial Environment Laboratory, Honohara 3-13, Toyokawa, Aichi, 442-8507, Japan*, T. Onishi, Y. Fukui, *Department of Astrophysics, Nagoya University, Chikusa-ku, Nagoya, 464-8602, Japan*.

The Lupus 3 molecular cloud has been surveyed for dense gas and dust cores and embedded objects in the radio ($H^{13}CO^+$ J =1–0 line and 1.3 mm continuum) and the infrared ($JHKL$ MN bands and H_2 v =1–0 s(1) line) wavelengths. These observations resulted in finding a filamentary cloud, three dense cores, an embedded mm source, and an associated jet-like object. The properties of the 3 dense cores are similar to those of Taurus, and two of them are likely to be prestellar cores while the other one exhibits ongoing star formation with the mm source. The spectral analysis of the mm source shows that it is a good candidate of class 0 object with low bolometric temperature (33 K) and non-detection in near- to mid-IR wavelength. The jet-like feature in K-band appear to be a reflection light coming from the mm source as it is not detected in the H_2 line.

The Lupus molecular cloud complex is known to be an active site of star formation. This cloud complex has been entirely surveyed in ^{12}CO [1], ^{13}CO [2], and $C^{18}O$ [3]. These unbiased cloud survey provided us homogeneous sample of dense cores unveiled from the star forming region. The Lupus clouds show a large variety in the star formation activity, for example, Lupus 3 is actively forming a cluster with more than 30 associated T Tauri stars (T association) [4] while Lupus 1 and 2 exhibit isolated star formations, on the other hand no sign of star formation is seen in Lupus 5. This particular activity in Lupus 3 is suggested to be induced by a shock from the Sco OB2 association [2].

Lupus 3 is a filamentary cloud whose elongation is nearly parallel to those of Lupus 2 and 4. The $C^{18}O$ core has a mass of $26 M_\odot$, length of 1.4 pc, and a density of 8.6×10^3 cm^{-3} [3]. In spite of its star formation activity, the associated stars are reported to be relatively old as 6.7 Myr in average [5]. The cloud has, however, a potential to form more cluster members with enough remaining mass. In order to investigate ongoing and near future star formation in this cloud, we have carried out a dense core survey in $H^{13}CO^+$ J =1–0 and dust continuum at 1.3 mm with the Swedish ESO Submillimeter Telescope (SEST).

As a result, 3 dense $H^{13}CO^+$ cores are found to be embedded in the $C^{18}O$ core (Fig. 1 left). The 3 cores are located not at the center of the $C^{18}O$ intensity peak but slightly offset while the T association is at the opposite side of the $C^{18}O$ core. None of the $H^{13}CO^+$ cores are associated with the young stars. Their mass, radius and density are estimated to be $4.7 M_\odot$, 0.04 pc, and 3.5×10^5 cm^{-3} in average, respectively, which are similar to those in Taurus [6]. These dense cores correspond to the infrared dark cores identified in JHK bands whose A_V is greater than 30 mag [7].

The 1.3 mm continuum emission map (Fig. 1 right) reveals thermal dust distribution in the core. It traces not only the $H^{13}CO^+$ dense cores but also the long filamentary structure along the elongation of the $C^{18}O$ core. The maxima of the continuum intensity well coincide with the positions of the 3 $H^{13}CO^+$ cores and the peak of the $C^{18}O$ where no $H^{13}CO^+$ emission is detected. This is probably due to the fact that $H^{13}CO^+$ is high density tracer with a critical density of 10^5 cm^{-3} while $C^{18}O$ and the dust continuum emissions are responsive to the column density.

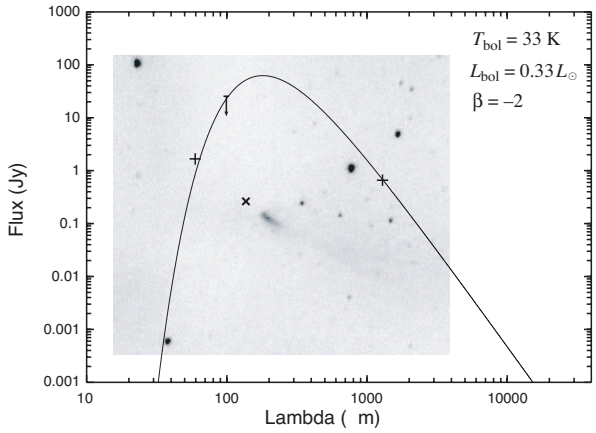

Figure 2: Foreground: The SED of the mm source. Tow data points at 60 μm and 1.3 mm are shown by the crosses and one upper limit at 100 μm is by the arrow. The best-fit gray body curve is drawn assuming $\beta = -2$. This gives bolometric temperature and luminosity of 33 K and 0.33 $L_\odot$, respectively. Background: The NTT K-band image near the mm source shown by the X mark. The size of the field is 1.1 arcmin^2. The jet-like elongated feature is visible pointing toward the mm source.

In addition to them, a mm point source embedded in one of the $H^{13}CO^+$ cores is detected at $(\alpha,\ \delta)_{2000}$ = (16:09:18.33, −39:04:51.6). This mm source is also detected by IRAS at 60 μm and an upper limit is given at 100 μm, although the spatial resolution of IRAS is not so good. From these flux densities, we investigate the spectral energy distribution (SED) as drawn in Fig. 2 foreground. Assuming the dust $\beta = -2$, we get the best-fit gray body function whose bolometric temperature and luminosity of $T_{\rm bol} = 33$ K and $L_{\rm bol} = 0.33\ L_\odot$, respectively. This cold temperature and faint luminosity suggest that they are low-mass young protostar such as class 0 object. The submm to bolometric luminosity ratio ($L_{\rm submm}/L_{\rm bol}$) is 3.4%,

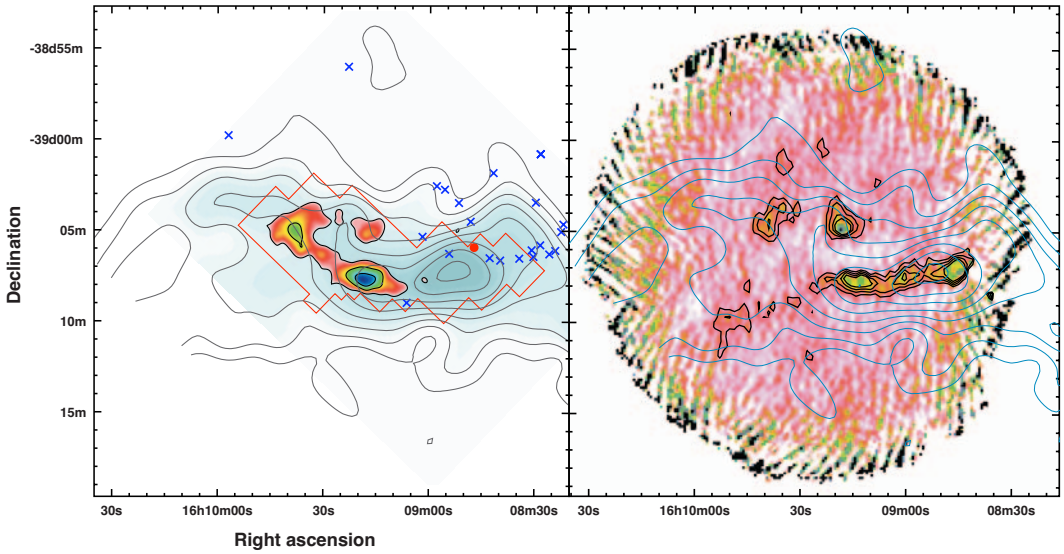

Figure 1: Results of the SEST observations in the Lupus 3 cloud. Left: $H^{13}CO^+$ integrated intensity map is shown as pseudo color image and contours (0.2 K km s^{-1} each) overlaid on the $C^{18}O$ contours (integrated intensity of 0.3 K km s^{-1} each) taken with the NANTEN telescope [3]. The border of the surveyed area is illustrated by the red lines. The blue crosses and red circle are T Tauri stars [5] and the IRAS point source 16054–3857. Right: 1.3 mm continuum SIMBA map is shown as pseudo color image. Contours are from 0.035 mJy to 0.14 mJy with 0.035 mJy steps excluding the border of the field of view. Overlaid are the the $C^{18}O$ contours as same as the left.

much greater than one of the suggested criteria of the class 0 object ($L_{\rm submm}/L_{\rm bol} > 0.5\%$) [8] which is a signature of deeply embedded source whose envelope mass is larger than the central stellar mass.

In order to ensure that this source is very cold and not visible at any shorter wavelength, we made infrared observations toward the mm source in JHK by ESO/NTT and MN by ESO/3.6m telescope, and L by ESO/VLT. We confirm no detection of the source and instead detected an elongated jet-like feature in the K-band. This was first found by Nakajima et al. [7] and suggested to be a jet coming out from an unknown embedded source, and is confirmed to be located near the mm source (Fig. 2 background). Further follow-up observation by the Subaru telescope reveal, however, that the jet-like feature is not detected in H_2 v =1–0 s(1) line, while the HH 78 is detected downstream from the mm source by 1.1 arcmin. These results imply that the jet-like feature is not the shock excited emission but instead reflection light of the central object as seen through a cavity created by the jet as indicated by the HH object.

Taking into all above, the mm source is very likely to be a class 0 object with the cold SED associated with the jet and embedded in the dense core. The other 2 $H^{13}CO^+$ dense cores are prestellar cores and will possibly form stars near future since they have enough mass and density. The sites of ongoing and future star formation seem to have propagate toward east from the position of currently visible T association. We concluded that Lupus 3 is still active in star formation as shown by the good candidate of class 0 object and the $H^{13}CO^+$ dense cores.

References

[1] Tachihara, K., Toyoda, S., Onishi, T., et al. 2001, PASJ, 53, 1081

[2] Tachihara, K., Dobashi, K., Mizuno, A., Ogawa, H., & Fukui, Y. 1996, PASJ, 48, 489

[3] Hara, A., Tachihara, K., Mizuno, A., et al. 1999, PASJ, 51, 895

[4] Krautter, J. 1991, in *Low Mass Star Formation in Southern Molecular Clouds*, ed. B. Reipurth, ESO Scientific Report No. 11, 127

[5] Hughes, J., Hartigan, P., Krautter, J., & Kelemen, J. 1994, AJ, 108, 1071

[6] Onishi, T., Mizuno, A., Kawamura, A., Tachihara, K., & Fukui, Y. 2002, ApJ, 575, 950

[7] Nakajima, Y., Nagata, T., Sato, S. et al. 2003, AJ, 125, 1407

[8] André, P., Ward-Thompson, D., Barsony, M. 2000, Protostars and Planets IV, 59