Nobeyama 45m telescope legacy project: Line survey

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<Abstract> We started a new line survey project in Dec. 2007. The target astronomical sources are the interesting low or high-mass star forming regions (L 1527, L1157 B1, and G28.34+0.06), and the galaxies (NGC 1068, NGC 253, and IC 342). Many molecules were detected: Various carbon-chain molecules in L 1527, organic molecules and PN in L 1157 B1, organic molecules and deuterated molecules in G28.34+0.06, and basic molecules including strong CN in NGC 1068.

Introduction Line surveys are of fundamental importance in astronomy not only for complete understanding of molecular abundances in representative sources, but also for finding out new observational tools (spectral lines) probing interstellar medium and star formation. We started a new line survey project in Dec. 2007. At present we are continuing the observations in the fifth year. We plan to complete the main part of the project in this observational season (until May 2012).

The target sources are the low-mass star forming region in L1527, the shocked region in L1157 B1, the infrared dark clouds G28.34+0.06, and the external galaxies NGC 1068, NGC 253, and IC 342. With the new receivers at the 3 mm region installed on the 45 m telescope (Nakajima et al. 2008), the frequency range from 78 to 117 GHz can be surveyed with much higher sensitivity than the previous observations with the old receivers. The new IF system, the new AD converters (4 GHz / 3 bit), the new spectrometers (max 2 GHz bandwidth x 16), and the new related softwares are available from Dec. 2010. This new system accelerated the survey, though we need further improvements.

The results will also provide us with useful templates for planning the observations with ALMA (Atacama Large Millimeter/submillimeter Array), which started the partial operation in Sept. 2011.

Results and discussion The main results until the fourth year are as follows.

(1) Low-mass star-forming region L1527: Generally carbon-chain molecules had been thought to be abundant in young dark clouds without star formation. L1527 is an interesting object, because the abundances of carbon-chain molecules are high, though this source is a low-mass star forming region (Sakai et al. 2008). The survey was done from 83 to 117 GHz, but the noise level is not yet uniform. We detected many lines from 39 species including various carbon-chain molecules, isotopic species (D, ^{13}C) of some carbon-chain molecules, and unidentified species, etc.

(2) Shocked region L1157 B1: L1157 B1 is a prominent region of interactions between a molecular outflow from the protostar and ambient clouds (Umemoto et al. 1992 and Mikami et al. 1992). This is an ideal region to study shock chemistry selectively, because this region is spatially separated from the protostar. The survey was finished from 78.1 to 115.5 GHz with the rms noise level of 5 mK

(T_A^*). As a result we could obtain a complete data of shock chemistry in the 3 mm region: We detected 130 lines from 44 species including CH_3CHO, CH_2DOH, carbon-chains CCS and C_2H, and PN. PN was unexpectedly detected (Yamaguchi et al. 2011), and it may be produced via PH_3 evaporated from grain (Charnley and Millar 1994). The preliminary results were published by Sugimura et al. (2011), and the data paper was accepted for publication (Yamaguchi et al. 2012).

(3) Infrared dark clouds G28.34+0.06 (possible high-mass star forming regions): In this source three interesting positions called MM1, MM4, and MM9 were selected, and a shallow survey was done from 86 to 98 GHz. The survey is continuing to cover from 80 to 110 GHz. Toward MM1 and MM4 line wings were found in HCO^+, HCN, SiO, CS, and CH_3OH. These wings indicate outflow activities. In addition, CH_3CHO is detected only in MM1 and MM4, though N_2D^+ was detected only in MM9. CH_3CHO may be evaporated from grain by star formation activities, and deuterium in N_2D^+ is thought to be concentrated in cold environment. Based on these results, MM1 and MM4 are thought to be warm, active, and more evolved objects.

(4) External galaxies: NGC 1068 is a nearby gas-rich galaxy with X-ray radiation from active galactic nucleus (AGN), and NGC 253 and IC 342 are also nearby gas-rich galaxies with prototypical starbursts. These galaxies are useful to study the effects of X-ray and UV radiation to molecular abundances. The survey was finished from 85 to 116 GHz with the rms noise level of a few mK (T_A^*). As a result we could obtain a complete data of these galaxies in the 3 mm region (Figure 1): We detected 21-23 species depending on the galaxies including several new detections (e.g. cyclic-C_3H_2, $H^{13}CN$, C_2H, SO, and CH_3CN in NGC 1068). We found that the intensities of HCN and CN relative to ^{13}CO are significantly strong in NGC 1068 compared to those in NGC 253 and IC 342. The preliminary results were published by Nakajima et al. (2011).

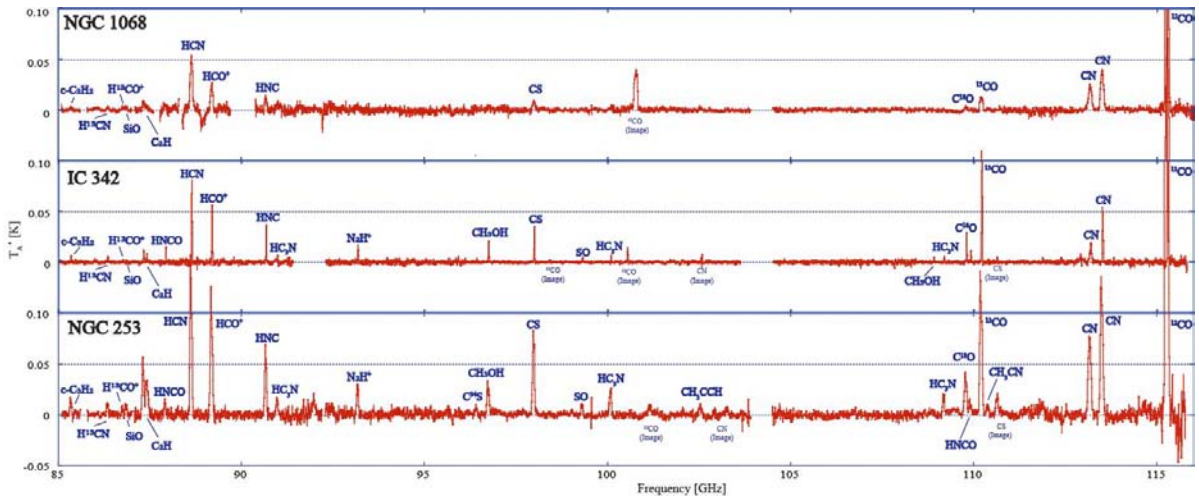

Figure 1: Spectra from 85 to 116 GHz obtained toward the external galaxies

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