Mapping Spectral Line Survey toward Nearby Galaxies with LST

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Introduction

The Large Submillimeter Telescope (LST) is one of the best telescope for mapping spectral line survey toward nearby galaxies, because of its' large field of view and large collecting area. Chemical compositions revealed by the spectral mapping observations allow us to study evolutionary stages of giant molecular clouds (GMC) and dynamical effect on the GMCs. Understanding formation and evolution of the GMC is crucial to explore the evolution of galaxies. Recent observations with radio interferometers such as PdBI and ALMA show that GMCs possess different physical properties from region to region even in a single galaxy (e.g. Colombo et al. 2014, Egusa et al. 2018). For example, a size of GMCs is found to be larger in spiral arms than inter-arm regions on average. Star formation efficiencies (SFE) also tend to be higher in spiral arms than inter-arm regions (Hirota et al. 2018). Moreover, velocity dispersions are reported to be higher in bar regions than the other regions, indicating prominent turbulence due to shocks induced by non-circular motion in bar regions. These different physical properties among the GMCs are thought to be originated by gas dynamics in the spiral galaxies. On the other hand, it is still under discussion how gas dynamics changes the GMC properties and how it affects star formation processes in the GMCs. To answer these questions, an astrochemical approach is very useful.

As inferred from astrochemical studies for Galactic sources, chemical compositions often tell us much more about physical conditions of target sources than conventional physical parameters such as mass, density, and temperature. For example, dynamical evolution of starless cores has been studied on the basis of chemical compositions, which gradually change with an age of a starless core (e.g. Suzuki et al. 1992; Caselli et al. 2002). In shocked regions induced by an outflow from a protostar, the chemical composition is affected by molecular species liberated from ice on dust, such as CH_3OH and SiO (e.g. Mikami et al. 1992; Bachiller et al. 1997). Thus, these molecules are usually considered as tracers of the interstellar shock. Moreover, characteristic chemical compositions are known in photodissociation regions under strong UV radiation (e.g. Tielens and Hollenbach 1985). Therefore, these chemical features are used as tracers of evolution and environments in Galactic star formation studies.

On the other hand, it is difficult to resolve a molecular cloud in the nearby spiral galaxy at a scale of a molecular cloud core as in the case of Galactic studies even with

ALMA. The chemical compositions observed toward external galaxies are 'average' chemical compositions of a number of giant molecular clouds (GMCs). Therefore, they cannot directly be discussed on the basis of astrochemical concepts established in nearby molecular clouds in our Galaxy. Although chemical differentiation is recognized among the nuclear regions with different activities such as active galactic nuclei and starburst, chemical differentiation is still unknown in disk regions of nearby galaxies (Watanabe et al. 2014, 2016). For establishing chemical diagnostics in external galaxies, it is important to reveal chemical compositions in disk regions of nearby galaxies by mapping spectral line survey.

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With the mapping spectral line survey, we can address following questions.

1. Chemical Characteristics of Giant Molecular Clouds in the Arm, Inter-arm, and Bar regions

Chemical compositions of GMCs vary depending on density, temperature, cosmic-ionization rate, and UV radiation, as well as evolutionary stages, while it is reset by destruction of molecules by the UV radiation. Harada et al. (in prep.) reported that duration time of a UV-shielded phase significantly affects molecular abundances of GMCs by using a time-dependent gas-grain chemical model. The chemical clock would be controlled by a size of a molecular cloud and strength of turbulence, because these parameters determine traveling time of molecular gas from the inner part to the surface of the cloud. In addition, enhancements of shock tracer molecules such as CH_3OH and SiO have been reported in shocked regions of the bar (Meier et al. 2005; Usero et al. 2008) and merging galaxies (Saito et al. 2017; Ueda et al. 2017) at a scale of 100 pc. Through the mapping spectral line survey, we can explore the average view of chemical compositions among different regions of galaxies and discuss the origin of the difference on the basis of chemical evolution and dynamics.

2. Radial Gradient of Chemical Composition

In disk galaxies, a molecular gas fraction relative to the total amount of gas, including atomic and molecular gas, is known to decrease with the galactocentric distance. Although the origin of this radial dependence is still under debate, the molecular gas fraction is expected to change the chemical composition of the molecular clouds. In addition, it is also known that the elemental abundance of heavy elements decrease with the galactocentric distance. Nishimura et al. (2016a,b) reported that abundances of nitrogen bearing molecular species such as HCN and N_2H^+ tend to be lower than those of other molecular species in molecular clouds in LMC and a dwarf galaxy IC10. Since the elemental abundance of nitrogen is lower than other elements in these galaxies, they concluded that the lower abundances of nitrogen bearing species are directly originated from the lower elemental abundance of nitrogen. Therefore, we can estimate variation of elemental abundances along the radial direction of galaxies through the chemical compositions. Since the elemental abundance reflects star formation history, we can discuss the local star formation history in galaxies.

3. Molecular Abundance Averaged over a Whole Galaxy

The molecular abundance obtained by averaging over a whole galaxy is an ideal template of molecular abundances in the local galaxies. It can be used to compare molecular abundance of high-redshift galaxies observed with the ALMA, since their structures cannot usually be resolved. By such comparisons, we can explore the difference of physical environment and elemental abundance between nearby galaxies and high-redshift galaxies.

Requests for the instruments

For efficient mapping spectral line survey observations, we need wideband and multi-pixel heterodyne receivers to cover wide frequency ranges and spatial areas. For example, we can observe almost all the 3 mm band (75 – 115 GHz) with only two frequency settings, if the IF bandwidth is about 10 GHz per sideband. In order to make use of the wide IF bandwidth, we also need wide-band spectrometers covering all the IF bandwidth. In addition, frequency resolution of 30 kHz is necessary for the spectrometer by taking into account of the mapping spectral line survey toward the Galactic sources. When we observe dark clouds in our Galaxy, for instance, we need the velocity resolution of 0.1 km/s which corresponds to 30 kHz at the 3 mm band. For the accurate evaluation of column densities, temperatures, and number density of H_2 by radiation transfer calculation, we need multi-transition observations. These chemical compositions and physical conditions are important to compare with chemical network calculations. Therefore, we need receivers which cover the frequency ranges of ALMA Band 2, 3, 4, 5, 6, and 7.

References:

Bachiller et al. 1997, ApJ, 487, L93
Caselli et al. 2002, ApJ, 572, 238

Colombo et al. 2014, ApJ, 784, 3
Egusa et al. 2018, ApJ, 854, 90
Hirota, A. et al. 2018, PASJ, 70, 73
Meier et al. 2005, ApJ, 618, 259
Mikami et al. 1992, ApJ, 392, 87
Nishimura et al. 2016a, ApJ, 818, 161
Nishimura et al. 2016b, ApJ, 829, 94
Saito, T. et al. 2017, ApJ, 834, 6
Suzuki et al. 1992, ApJ, 392, 551
Tielens and Hollenbach 1985, ApJ, 291, 722
Ueda et al. 2017, PASJ, 69, 6
Usero et al. 2006, A&A, 448, 457
Watanabe et al. 2014, ApJ, 788, 4
Watanabe et al. 2016, ApJ, 819, 144