論文の内容の要旨

Physical Conditions of Molecular Gas in Nearby Merging Luminous Infrared Galaxies
(近傍高光度赤外線相互作用銀河の分子ガスの物理状態)

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Gravitational interactions between gas-rich galaxies are thought to play an important role in the formation and evolution of galaxies. Such gas-rich galaxy mergers trigger bursts of star formation and efficient accretion to the central supermassive black holes, leading them to dusty brighter populations, so-called (ultra-)luminous infrared galaxies (U/LIRGs). As a tracer of the fuel for the IR engines hidden behind large column of dust, molecular line emissions at longer wavelengths (millimeter, submillimeter, and far-IR) are suitable to investigate U/LIRG activities directly. In this Thesis, we investigate physical conditions of molecular gas in two nearby merging LIRGs, NGC 1614 and VV 114, through high angular resolution and high sensitivity observations of multiple molecular diagnostic lines; (1) CO (four transitions), (2) CH_3OH (two blended transitions), and (3) HCN (three transitions) and HCO^+ (three transitions) rotational lines supplemented with other lines and continuum emission with Atacama Large Millimeter/submillimeter Array (ALMA) and Very Large Array.

NGC 1614 is one of the nearby LIRGs. Since this system is thought to be a remnant stage of a gas-rich galaxy merger without any heavily obscured AGN or bright AGN activity, we can use this galaxy as a template of starburst-dominated galaxies. The another target, a nearby mid-stage merging LIRG VV 114, is known to have a characteristic dust and gaseous filament (~ 6 kpc length) across the progenitor's galaxies. The filament harbors three distinctive regions; a hard X-ray detected AGN, starbursting clumps, and Overlap region at the collision front. Taking advantage that these three regions can be observed simultaneously by small fields of view of submillimeter interferometers, we can test molecular diagnostics.

High-resolution, high-sensitivity, and uv-matched ALMA observations allow us to solve excitation conditions of these molecules under local thermodynamical equilibrium (LTE) or non-LTE assumptions in order to parameterize and differentiate thermal and chemical properties of molecular gas. We found that (1) CO spectral line energy distribution up to J_{upp} = 6 in NGC 1614 can be explained by two-phase molecular gas ISM (> 70 K and ~ 19 K), which is consistent with observed two-phase dust spectral energy distribution (~ 110 K and ~ 35 K). PDR is the main heating source for the cold ISM, while mechanical heating from supernovae or stellar winds is required for the warm ISM. (2) CH_3OH abundance (X_{CH3OH}) peaks at the extended (a few kpc) Overlap region, where is located between the progenitor's disks of VV 114. The abundance is almost an order of magnitude larger than the nuclear regions. This indicates that the presence of AGN and intense starburst activities suppress CH_3OH at the nuclear regions by strong photodissociation (i.e., efficient destruction) and/or desorption of the precursor molecule CO (i.e., inefficient production), and merger-induced shocks enhance CH_3OH at the Overlap region. The extended, bright CH_3OH emission cannot be explained by hot-core environments. (3) Surface density of star formation rate (Σ_{SFR}) strongly correlates with the excitation conditions and flux densities of HCN and HCO^+, indicating that star formation activity may govern the physical properties of dense gas ISM in the filament of VV 114, although the putative AGN position doesn't fit to this scenario. The AGN, which shows relatively low Σ_{SFR}, has the highest excitation ratios (i.e., high T) and HCN/HCO^+ ratios (i.e., high X_{HCN}), showing completely different thermal and chemical properties from star-forming regions. In addition, we found that the star formation efficiency doesn't simply correlate with the dense gas fraction. By adopting the turbulence-regulated star formation model, we suggest that the Overlap region has diffuser and more turbulent dense gas properties relative to dense gas at the eastern nucleus. This is consistent with the shock interpretation of the CH_3OH enhancement at the Overlap region.

Our studies succeeded in distinguishing and interpreting molecular gas properties affected by AGN, star formation, and merger-induced shocks took place in nearby merging LIRGs.