A Framework for Probing Dust Clump Properties in High-Redshift Galaxies Through Dust and Chemical Evolution Modeling

Ryusei Kano[1], Tsutomu T. Takeuchi[1,2]

[1]Nagoya University, Japan, [2]The Institute of Statistical Mathematic, Japan.

In the context of galaxy evolution studies, interstellar dust plays a fundamental role in shaping various physical processes, notably affecting the spectral energy distribution (SED), which characterizes how energy is emitted across different wavelengths, as well as influencing the star formation history. To capture these processes comprehensively, this study employs a theoretical framework that simultaneously models both chemical and dust evolution. Here, chemical evolution refers to the progressive change in elemental abundances due to stellar activity, while dust evolution accounts for the formation, growth, and destruction of dust grains within the interstellar medium.

Based on this framework, we developed a galaxy SED model capable of reproducing the observed SEDs of local (nearby) galaxies. However, when extending this model to galaxies at high redshift (e.g., $z\sim8$), modifications become necessary to account for intrinsic differences in their physical properties. This work focuses on refining the theoretical formulation of the SED model to improve its applicability to extremely high-redshift galaxies.

A key refinement involves the treatment of dust-rich molecular clouds—often referred to as "clumps"—surrounding newly formed stars. These clumps are assumed to be spherically symmetric for radiative transfer calculations. Given that high-redshift galaxies are generally more compact in structure, we posit that the dust clumps in these environments possess higher internal densities than those in nearby galaxies. By decoupling the clump radius from the global galactic properties and enhancing the dust number density within these regions, the model more accurately reproduces the elevated dust emission seen in observations of early galaxies.

Furthermore, we have implemented Markov Chain Monte Carlo (MCMC) methods to optimize model parameters more robustly. This statistical approach allows for a more precise exploration of parameter space, enabling tighter constraints on physical properties such as clump density, size, and dust-to-gas ratio. As a result, the improved model yields simulations that align more closely with observed SEDs and supports the interpretation that early galaxies harbor dust clumps with significantly higher number densities than their local counterparts.