Probing protocluster assembly through cold molecular gas at z = 4.3 with ALMA

How the environment impacts galaxy evolution remains a fundamental question at early cosmic times, when the first massive structures were rapidly assembling. In the ΛCDM paradigm, cluster formation occurs through hierarchical assembly along cosmic filaments. These processes are expected to leave imprints that trace the history of galaxy formation. However, directly observing the fuel for this assembly, the cold molecular gas, remains a challenge.

Here, I present deep ALMA Band 1 observations of the CO(2–1) emission line in the massive protocluster SPT2349-56 at z = 4.3. This system is the most extreme star-forming overdensity known, only ~1.4 Gyr after the Big Bang. It hosts nearly 30 spectroscopically confirmed gas-rich galaxies within a compact region. While previous studies focused on high-excitation tracers, these new Band 1 data provide a more precise view of the cold molecular gas reservoir and how dense environments impact its availability.

We detect CO(2–1) emission in 14 out of the 29 confirmed members, at S/N>3, and provide stringent limits on the remaining sources. In parallel, we conduct a blind line search to identify additional low-excitation gas-rich emitters that may have been missed by high-excitation surveys. Using a conversion factor of $\alpha_{\mathrm{CO}} = 0.8$, we derive molecular gas masses ranging from 1.22×10^9 to $9.33 \times 10^{10}\ M_{\odot}$. These measurements are consistent with previous estimates, showing a mean agreement within 0.07 dex while providing more robust constraints on each member. Through comparison with existing FIR continuum, [CII], [CI], and high-J CO line data, the CO(2-1) analysis allows us to determine gas fractions, depletion timescales, and excitation conditions for individual galaxies.

This work provides key constraints on the regulation of gas supply mechanisms and star formation in star-forming galaxies residing in extreme environments at early cosmic times. This dataset serves as a benchmark for future studies of molecular gas in overdense regions.